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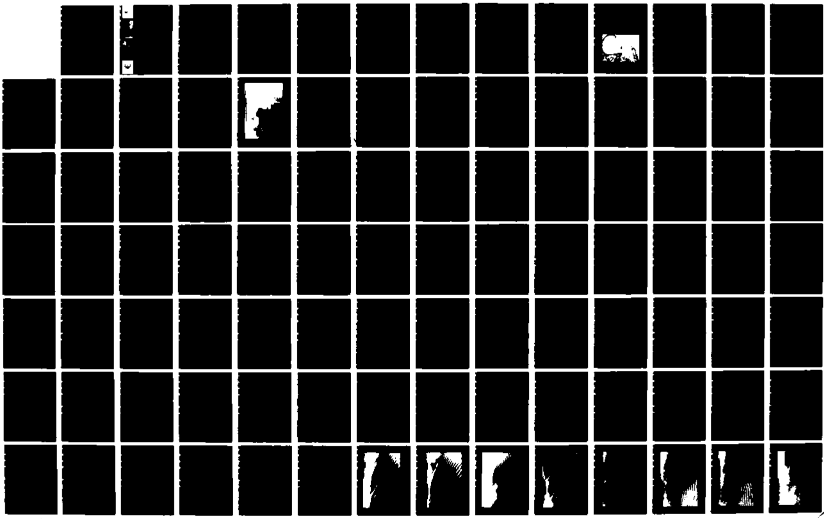

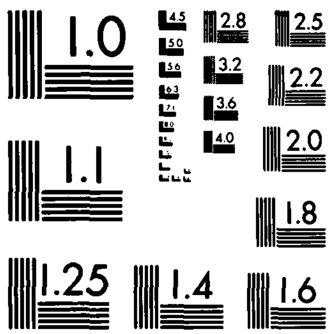

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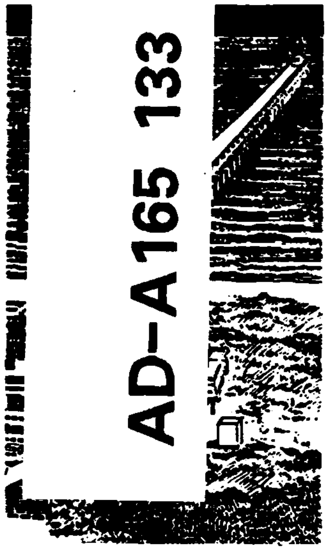

TECHNICAL REPORT CERC-85-7

FISHERMAN'S WHARF AREA, SAN FRANCISCO BAY, CALIFORNIA DESIGN FOR WAVE PROTECTION

Physical and Numerical Model Investigation

by

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October 1985
Final Report

Prepared for

US Army Engineer District, Los Angeles
Los Angeles, California 70053

and

US Army Engineer District, San Francisco
San Francisco, California 94105

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A physical model and a numerical model were used to investigate the design of proposed breakwater configurations for wave protection in the Fisherman's Wharf area, San Francisco Bay, California. A 1:75-scale (undistorted) physical model was used to determine wave conditions in the harbor for locally generated short-period wind waves and swell conditions entering through the Golden Gate. The model included the entire Fisherman's Wharf

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20. ABSTRACT (Continued).

area (Bordered by Pier 45 on the east and Municipal Pier on the west) and underwater contours in San Francisco Bay to a depth of 60 ft. A 40-ft-long wave generator, crushed coal sediment tracer material, and an automated data acquisition and control system were utilized in model operation. A hybrid finite element numerical model capable of calculating forced harbor oscillations for harbors of arbitrary shape and variable depth was used to calculate harbor resonance at Fisherman's Wharf. A numerical finite element grid was used to compute wave-height amplification factors and normalized maximum current velocities associated with the area's response to incident long-period waves ranging from 300 to 600 sec. A ship surge analysis was conducted for the ships moored along or near the Hyde Street Pier.

Principal conclusions from the physical model investigation for the 90 plans tested were:

a. Existing conditions are characterized by very rough and turbulent wave conditions in the various mooring areas of the harbor during periods of storm-wave attack.

b. For existing conditions, sediment in the Aquatic Park area migrated in both the easterly and westerly directions depending on the angle of wave approach. This movement occurred for only the most severe locally generated storm wave conditions from the various test directions and swell conditions approaching from Golden Gate.

c. The originally proposed improvement plan with the 1,450-ft-long solid outer breakwater with a 200-ft-wide entrance at Pier 45 (Plan 1) resulted in excessive wave heights in the harbor due to locally generated wave energy entering through the entrance.

d. Of all the improvement plans tested (Plans 1-90), the 1,560-ft-long outer solid breakwater configuration with the cumulative 400-ft segmented breakwater configuration at Pier 45 (Plan 78), was determined to be the optimum plan tested considering wave protection afforded the harbor and entrance, ease of navigation, and economics.

The observed long-period wave data analysis and harbor oscillation evaluation for Plan 78 indicated that harbor oscillations did not develop at periods less than 171 sec and the resonant peak of the fundamental mode of oscillation (228-sec period) decreased 15 to 20 percent throughout the inner harbor area. Ship surge motion results indicated that the resonant response of ships in the historic fleet was at periods lower than the fundamental mode of oscillation.

The combined results of the physical model study, harbor oscillation study, and ship response analysis for the historic fleet moored along the Hyde Street Pier provide a detailed analysis of short- and long-period wave activity and the resulting predicted ship response changes. In summary, Plan 78 was determined to be the optimum plan tested for short-period wave protection and did not result in significantly changed long-period harbor oscillation or ship mooring conditions.

PREFACE

Model investigations of the Fisherman's Wharf area, San Francisco Bay, California, were requested by the US Army Engineer District, Los Angeles (SPL), in a letter to the US Army Engineer Division, South Pacific (SPD), dated 13 January 1984. Authorization for the US Army Engineer Waterways Experiment Station (WES) to perform the study was granted by the Office, Chief of Engineers, US Army. Funds were authorized by SPL on 23 January, 14 March, and 27 April 1984. The Fisherman's Wharf project was under the jurisdiction of the US Army Engineer District, San Francisco (SPN), with engineering support provided by SPL.

Model studies were conducted at WES from January to May 1984 in the Wave Processes Branch (WPB), Wave Dynamics Division (WDD), Coastal Engineering Research Center (CERC), under the direction of Dr. R. W. Whalin, former Chief, CERC; Dr. L. E. Link, Jr., former Assistant Chief, CERC; Mr. C. E. Chatham, Jr., Chief, WDD; and Mr. D. G. Outlaw, Chief, WPB. The numerical model investigations were conducted by Mr. F. E. Sargent, Hydraulic Engineer, and the physical model investigation was conducted by Mr. E. R. Smith, Civil Engineer, Mr. M. G. Mize, Civil Engineering Technician, and Ms. M. L. Hampton, Computer Technician, under the supervision of Mr. R. R. Bottin, Jr., Project Manager. Mr. L. L. Friar was the Instrumentation Technician for the model study. This report was prepared by Messrs. Bottin, Sargent, and Mize.

Prior to the model investigations, Messrs. Bottin and Mize met with Mr. Dennis Thuet (SPN) and visited the Fisherman's Wharf area of San Francisco Bay to inspect the prototype site. During the investigation, liaison between SPN, SPL, and WES was maintained by conferences, telephone communications, and monthly progress reports. Messrs. Outlaw and Bottin attended a public meeting in San Francisco and presented model test results.

Visitors to WES to observe model operation and/or participate in conferences during the study were Mr. Robert Edmisten, SPD; Mr. Dennis Thuet, SPN; Mr. Tad Nizinski, Ms. Jane Fulton, and Mr. David Lau, SPL; Dr. Robert MacArthur, Hydrologic Engineering Center; and Mr. Vello Kiisk and Mr. John Kellog, Chief and Assistant Chief Port Engineer, respectively, Port of San Francisco.

COL Tilford C. Creel, CE, and COL Robert C. Lee, CE, were Commanders and Directors of WES during the conduct of the study. COL Allen F. Grum, USA, was Director of WES during the preparation and publication of this report. Mr. Fred R. Brown and Dr. Robert W. Whalin were Technical Directors.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4,046.856	square metres
feet	0.3048	metres
inches	2.54	centimetres
pounds (mass)	0.4535924	kilograms
square feet (US statute)	0.09290304	square metres
square miles (US statute)	2.589988	square kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

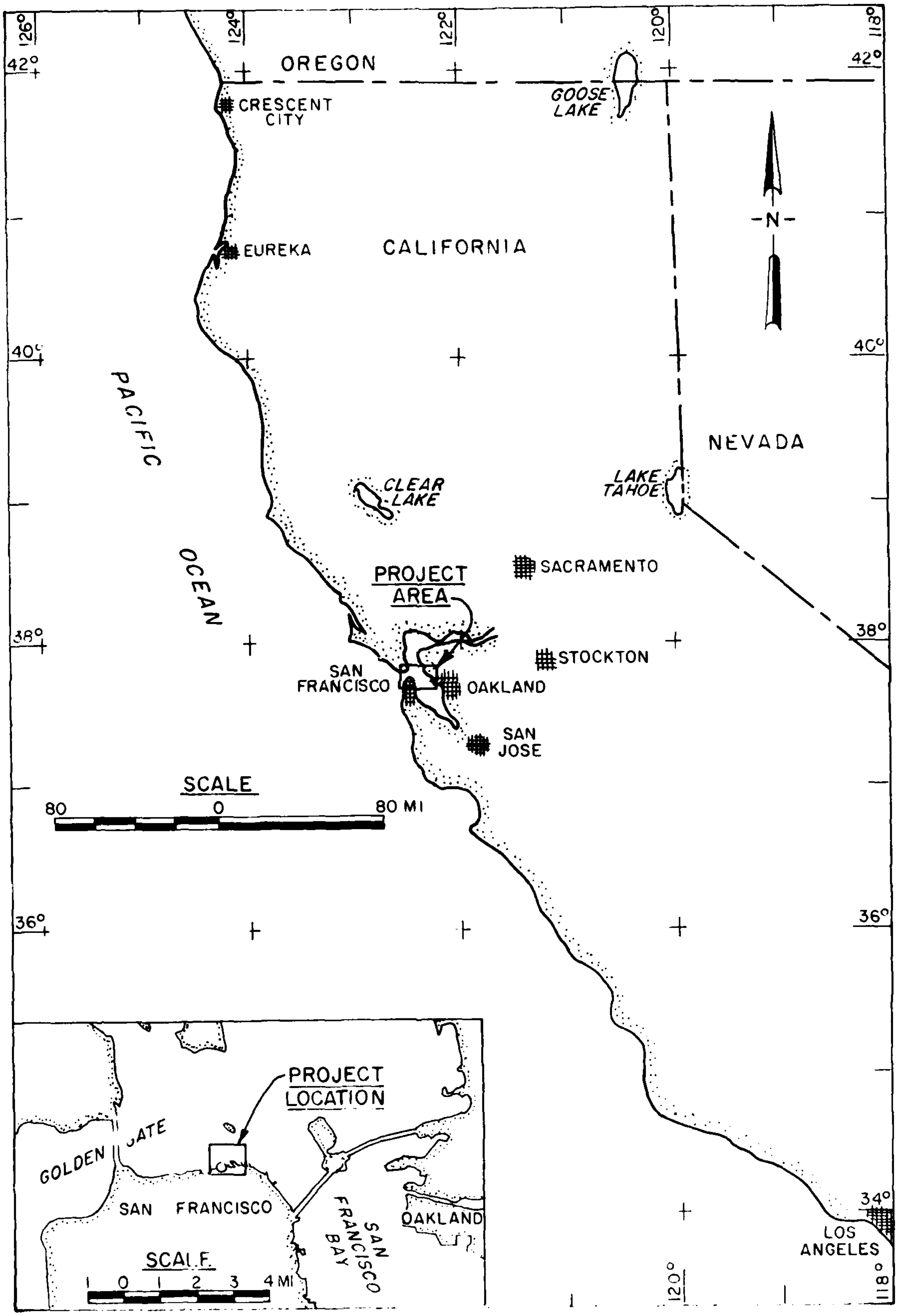

Figure 1. Project location

FISHERMAN'S WHARF AREA, SAN FRANCISCO BAY, CALIFORNIA

DESIGN FOR WAVE PROTECTION

Physical and Numerical Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Fisherman's Wharf area is located in San Francisco Bay near the Golden Gate (Figure 1) and is a well-defined segment of the San Francisco city waterfront. The area is bounded on the east by Pier 45 and on the west by the Municipal Pier. Existing development consists of a complex of commercial and recreational facilities (Figure 2).

2. For many years Fisherman's Wharf has been the center of the northern California commercial fishing industry. Data from the California Department

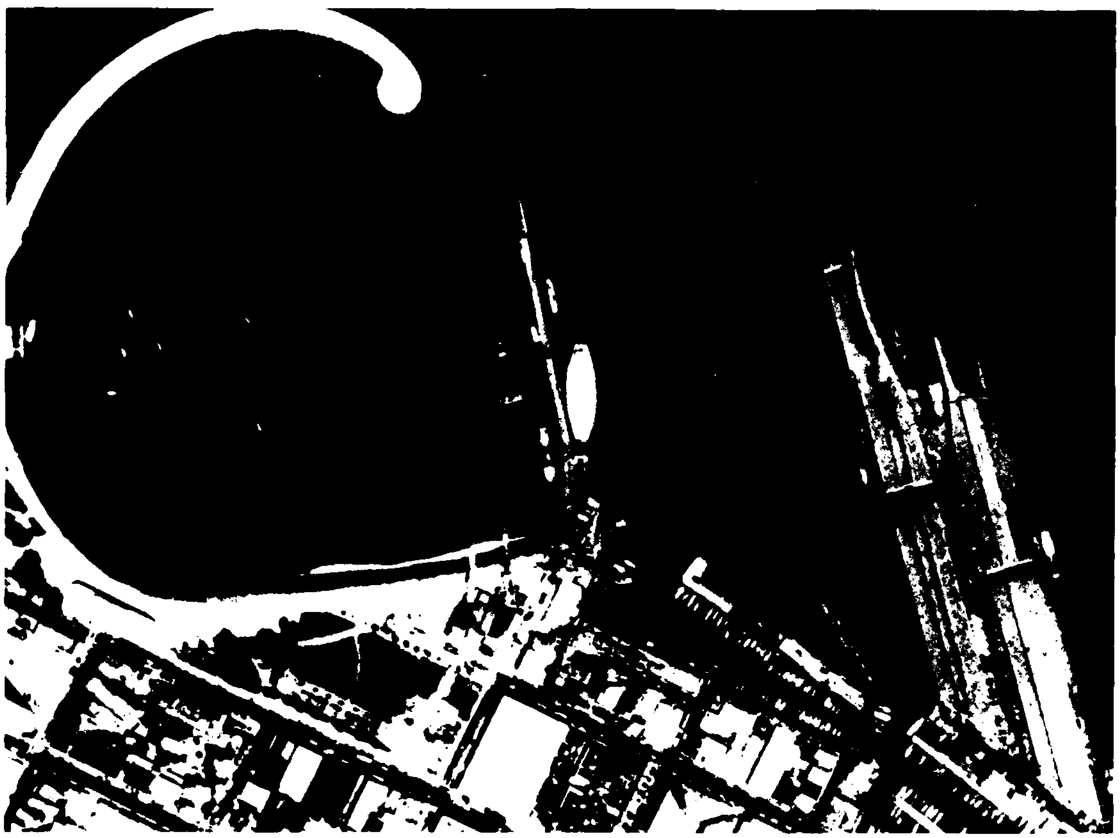

Figure 2. Aerial view of Fisherman's Wharf area

of Fish and Game indicate that about 16.8 million pounds* of fish were landed at Fisherman's Wharf in 1979 and the amount has increased by about 1 million pounds per year during the past 5 years (US Army Engineer District, San Francisco 1982). About 170 berths are located in the area for commercial fishing boats.

3. The Fisherman's Wharf area is a world-famed tourist attraction with a complex of recreational activities that receives in the tens of millions of visitors annually. The San Francisco Maritime State Historic Park is located on the Hyde Street Pier where five historic antique ships are on display to the public. Custody of this historic fleet has been transferred to the Golden Gate National Recreation Area. Excursion vessels provide waterfront tours of the area. Sport fishing is popular, and numerous boats engage in regular for-hire trips. The area encompasses many commercial businesses, including curio shops, restaurants, parks, sidewalk cafes, fishing shops, hotels, marinas, museums, and shopping complexes, clustered about the central attraction of the Wharf and its commercial fishing activities.

Problems and Needs

4. Although part of a densely developed, heavily populated area with a network of piers, wharves, and berthing areas, Fisherman's Wharf is essentially unprotected from wave damage. Minimal protection provided by timber piers has diminished with the removal of deteriorated sections. During winter storms, wave energy from the open ocean (entering through Golden Gate) and local storms (waves generated by winds across the extensive water surface of the bay), result in continual damage to fishing vessels and mooring facilities. Many fishermen have abandoned the harbor due to recurring boat damage. Waves have also caused damages to the historic vessels berthed in the area. Wave activity is relatively mild compared with the open coastline, but Fisherman's Wharf is the most exposed and vulnerable of small-craft harbors within San Francisco Bay with wave heights ranging up to 5.5 ft in the area (Assistant Secretary of the Army (ASA) 1983).

5. Recreational berthing within the city of San Francisco is limited

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

with only about 700 berths available, all of which are fully occupied. Improvements at Fisherman's Wharf could provide additional recreational facilities to meet the increasing demand for such in the area.

6. In summary, improvements are needed at the Fisherman's Wharf area to provide fishing vessel protection; historical vessel protection; and new, protected, recreational boating berths.

Proposed Improvements

7. Although numerous solutions to the problems and needs relating to harbor improvement in the Fisherman's Wharf area were analyzed, the most practical and feasible plan consists of a commercial fishing harbor enclosed by a concrete breakwater with solid and baffled sections to assure both adequate wave protection and water circulation (ASA 1983). This breakwater concept would enclose an area of about 27 acres between the Hyde Street Pier and Pier 45 and provide protection from waves generated by winds from northeast counterclockwise through west-northwest. A 10-ft-wide walkway on top of the breakwater would be included for pier fishing and sightseeing. Berthing space for approximately 350 small craft would be provided. Existing depths are adequate for light-draft vessels. The improved harbor would provide a physical framework for the development of onshore facilities related to commercial fishing and recreation.

Purpose of the Investigations

8. At the request of the US Army Engineer District, Los Angeles (SPL), and the US Army Engineer District, San Francisco (SPN), an investigation was conducted by the US Army Engineer Waterways Experiment Station (WES) to:

a. Determine, through the use of a physical hydraulic model:

   (1) The most economical breakwater configuration that would provide adequate protection for craft in the area from short-period waves.

   (2) The impact of reflections from the proposed breakwater with regard to erosion of the beach at Aquatic Park.

b. Determine, through the use of a numerical harbor oscillation model, the impact of the proposed structures with regard to harbor response due to wave excitation for long-period waves entering through the Golden Gate.

c. Determine, through the use of a numerical ship mooring analysis, the impact of the proposed structures on the motions of the historic vessels moored along or near the Hyde Street Pier.

d. Develop remedial plans, as necessary, to alleviate undesirable conditions.

Wave-Height Criteria

9. Completely reliable criteria have not yet been developed for ensuring satisfactory mooring conditions in small-craft harbors during attack by waves. For this study, however, SPL and SPN specified that for an improvement plan to be acceptable, maximum wave heights in the small-craft mooring areas should not exceed 1.0 ft, and maximum wave heights in the mooring area provided for the historic fleet should not exceed 1.5 ft.

PART II: SHORT-PERIOD WAVE TESTS

The Physical Model

Design of model

10. The physical model of the Fisherman's Wharf area (Figure 3) was constructed to an undistorted linear scale of 1:75, model to prototype. Scale selection was based on such factors as:

- a. Depth of water required in the model to prevent excessive bottom friction.
- b. Absolute size of model waves.
- c. Available shelter dimensions and area required for model construction.
- d. Efficiency of model operation.
- e. Available wave-generating and wave-measuring equipment.
- f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of short-period wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension*	Model: Prototype Scale Relation
Velocity	L**	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5,625$
Volume	L^3	$\forall_r = L_r^3 = 1:421,875$
Time	T	$T_r = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$

* Dimensions are in terms of length and time.
** For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

11. Some of the existing areas at Fisherman's Wharf include rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type of structure; thus the

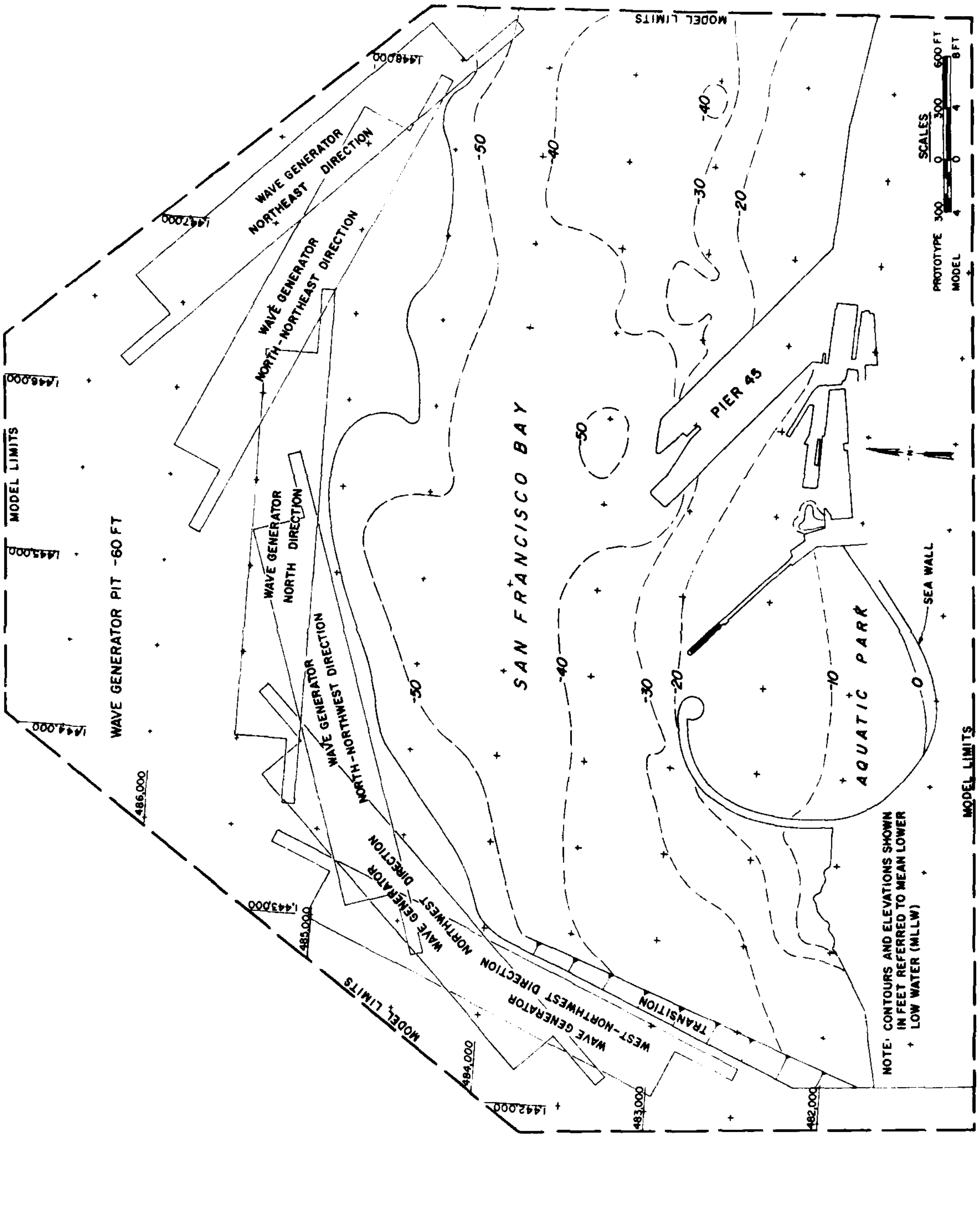

Figure 3. Model layout

transmission and absorption of wave energy became a matter of concern in design of the 1:75-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (Le Méhauté 1965). The transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations (Dai and Jackson 1966, Brasfeild and Ball 1967) at WES, this adjustment was made by determining the wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at Fisherman's Wharf, it was determined that a close approximation of the correct wave-energy transmission characteristics would be obtained by increasing the size of the rock used in the 1:75-scale model to approximately one-and-one-half times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the Fisherman's Wharf model, the rock sizes were computed linearly by scale, then multiplied by 1.5 to determine the actual sizes to be used in the model. The improvement plans for Fisherman's Wharf included the use of concrete-pile breakwaters and baffled sections. These structures (except for the baffled openings) were considered to be impervious and were constructed of wood and/or Plexiglas.

12. The existing area consists of a complex system of piers, wharves, and pilings. These structures were reproduced in the model. The decking of the piers and wharves was constructed with Plexiglas, and the massive piling systems were constructed with metal and/or plastic rods. Firewalls, wave baffles, and solid landfills were also constructed beneath the piers and wharves with metal, concrete, and/or Plexiglas to represent the prototype features.

13. Ideally, a quantitative, three-dimensional, movable-bed model investigation would best determine the impacts of the proposed structures with regard to possible erosion at Aquatic Park. However, this type of model investigation is difficult and expensive to conduct, and each area in which such an investigation is contemplated must be carefully analyzed. In view of the

complexities involved in conducting movable-bed model studies, and due to limited funds and time for the Fisherman's Wharf project, the model was molded in cement mortar (fixed bed) at an undistorted scale of 1:75 and a tracer material was obtained to qualitatively determine the degree of erosion and accretion at the Aquatic Park shoreline for the optimum improvement plan.

The model and appurtenances

14. The model reproduced the entire Fisherman's Wharf area, which included approximately 6,400 ft of the San Francisco Bay shoreline that extended from a point east of Pier 45 to a point west of the Municipal Pier, and underwater contours in the bay to an offshore depth of 60 ft. The total area reproduced in the model was approximately 6,000 sq ft which represents about 1.1 square miles in the prototype. A general view of the model is shown in Figure 4. Vertical control for model construction was based on mean lower low water (mllw).* Horizontal control was referenced to a local prototype grid system.

15. Model waves were generated by a 40-ft-long wave generator with a trapezoidal-shaped, vertical-motion plunger. The vertical movement of the plunger caused a periodic displacement of water incident to this motion. The length of the stroke and the frequency of the vertical motion were variable over the range necessary to generate waves with the required characteristics. In addition, the wave generator was mounted on retractable casters which enabled it to be positioned to generate waves from the required directions.

16. An Automated Data Acquisition and Control System (ADACS), designed and constructed at WES (Figure 5), was used to secure wave-height data at selected locations in the model. Basically, through the use of a minicomputer, ADACS recorded onto magnetic tape the electrical output of parallel-wire, resistance-type wave gages that measured the change in water-surface elevation with respect to time. The magnetic tape output of ADACS was then analyzed to obtain the wave-height data.

17. A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to damp any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

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* All elevations (el) cited herein are in feet referred to mean lower low water (mllw) unless otherwise defined.

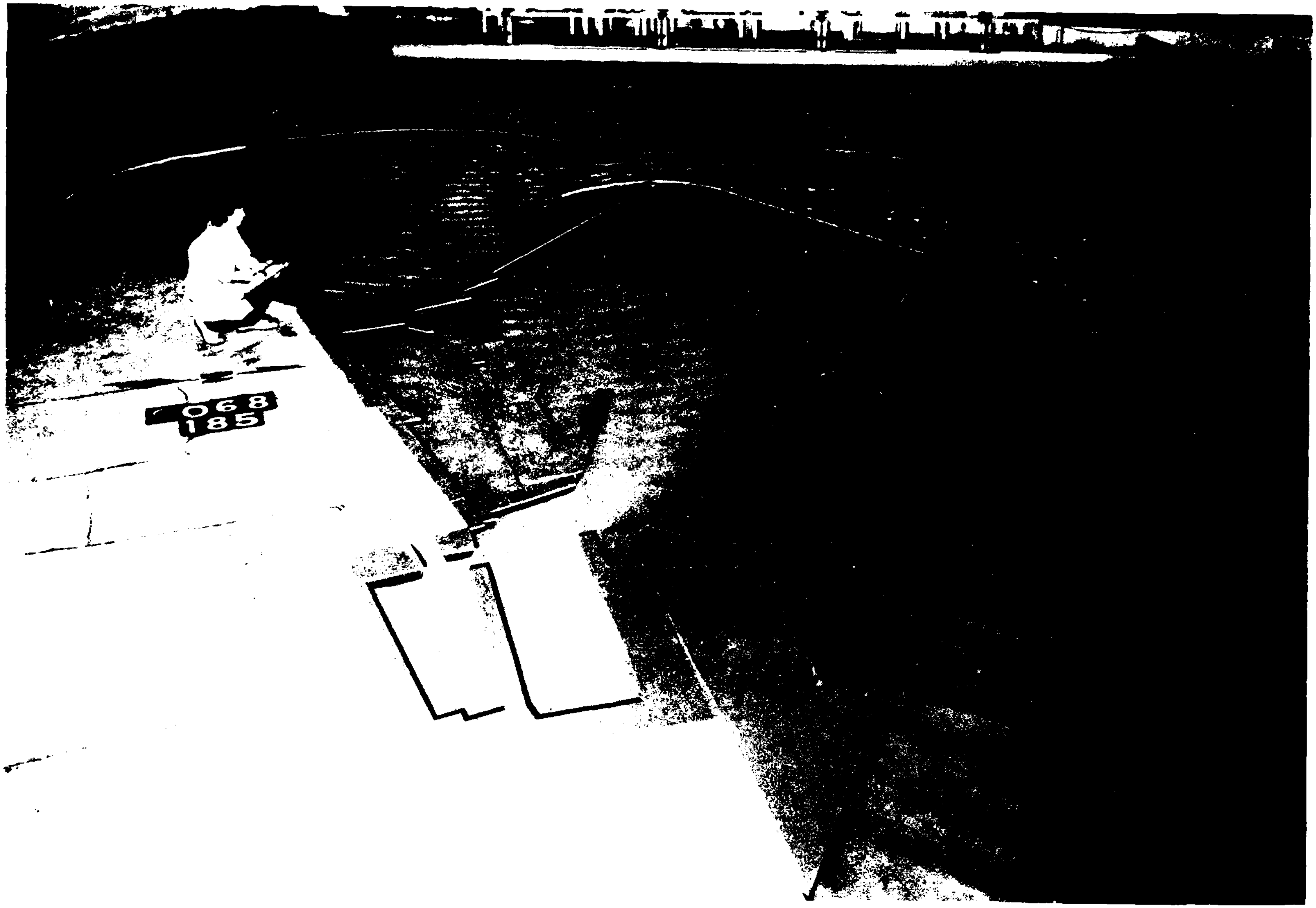

Figure 4. General view of model

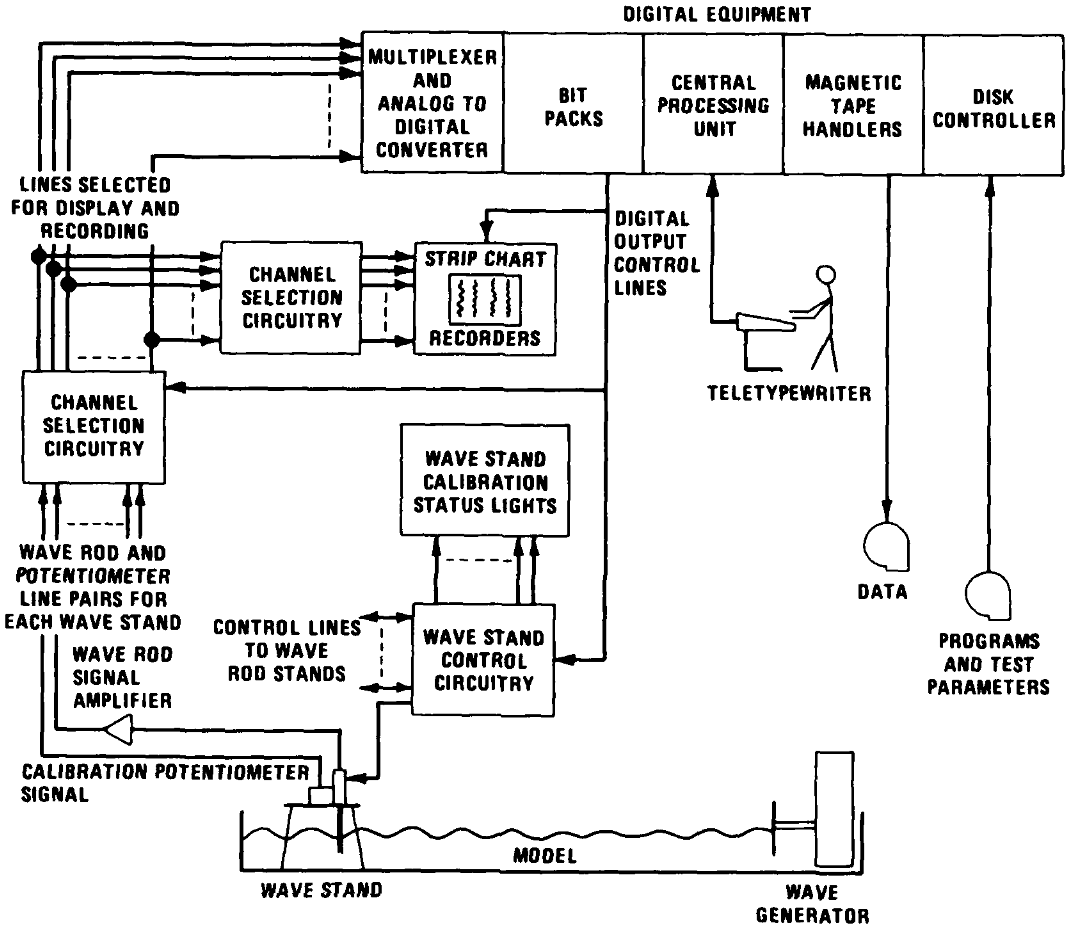

Figure 5. Automated Data Acquisition and Control System (ADACS)

Selection of tracer material

18. As discussed previously in paragraph 13, a fixed-bed model was constructed and a tracer material selected to qualitatively determine the degree of erosion and accretion on the shoreline of Aquatic Park. The tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation or model law among the four basic scale ratios; i.e. the horizontal scale λ, the vertical scale μ, the sediment size ratios η_D, and the relative specific weight ratio η'_γ (Figure 6). These relations were determined experimentally by Noda using a wide range of wave conditions and beach materials and are valid mainly for the breaker zone.

19. Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:75 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). [illegible] fixed-bed model of Fishermans's Wharf was undistorted to allow [illegible]

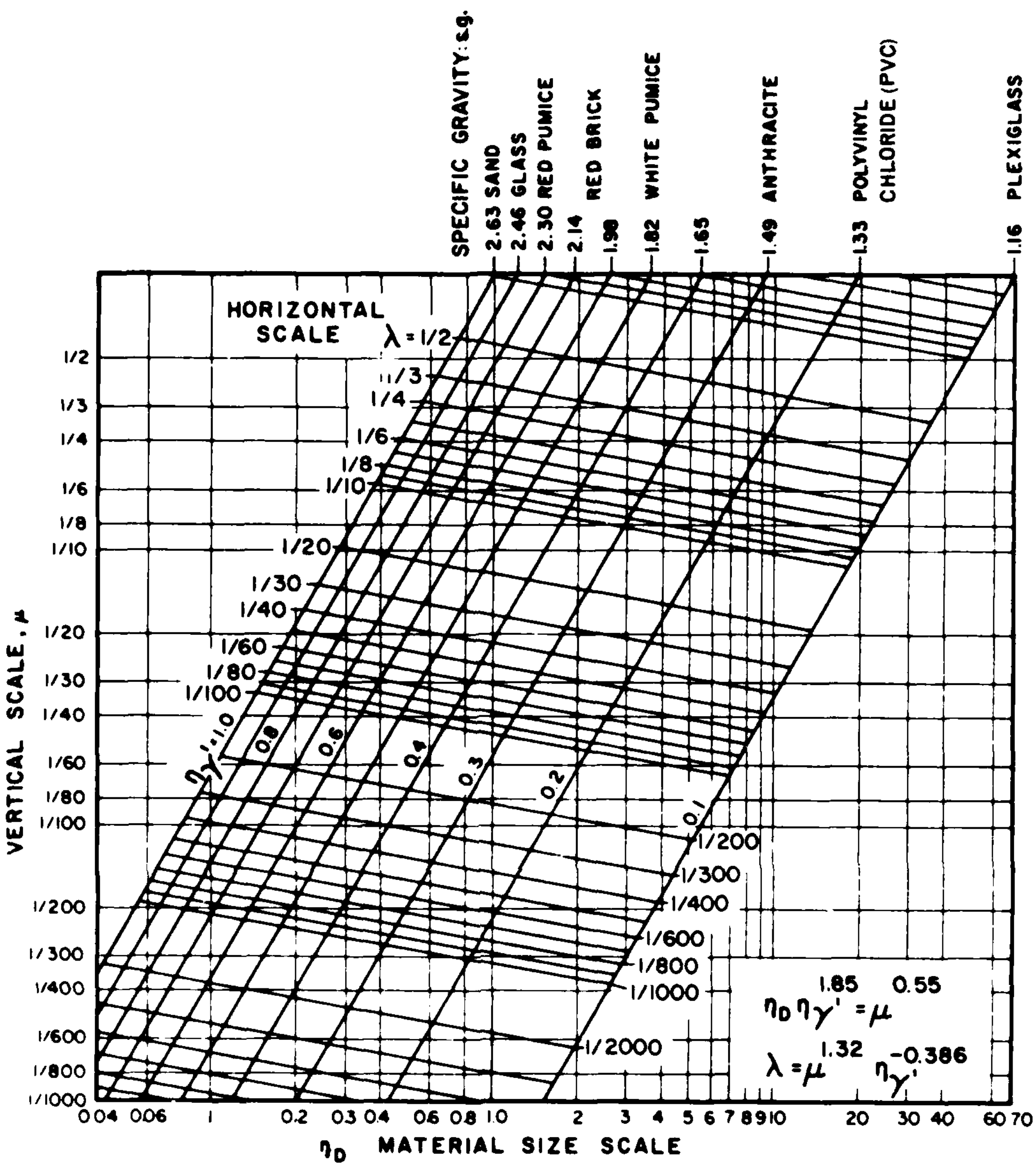

Figure 6. Graphic representation of model law
(from Noda 1972)

reproduction of short-period wave and current patterns, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.21 mm specific gravity = 2.7) and assuming the horizontal scale to be in similitude (i.e. 1:75), the median diameter for a given specific gravity of tracer material and the vertical scale were computed. The vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that a crushed-coal tracer more nearly represented the movement of prototype sand. Therefore quantities of crushed coal (specific gravity = 1.30 ; median diameter, D_{50} = 0.58 mm) were selected for use as a tracer material.

Test Conditions and Procedures

Selection of still-water level

20. Still-water levels (swl's) for harbor wave-action models are selected so that the various wave-induced phenomena dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the harbor area, the overtopping of harbor structures by the waves, the reflection of wave energy from harbor structures, and the transmission of wave energy through porous structures.

21. In most cases it is desirable to select a model swl that closely approximates the higher water stages which normally occur in the prototype for the following reasons:

- a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.
- b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind tide and shoreward mass transport.
- c. The selection of a high swl helps minimize model scale effects due to viscous bottom friction.
- d. A model investigation tends to yield more conservative results when a high swl is selected.

22. Swl's of 0.0 ft. and +5.7 ft were selected by SPL for use during model testing. The lower value (0.0 ft) represents mllw and the higher value (+5.7 ft) represents mean higher high water.

Factors influencing selection of test wave characteristics

23. In planning the testing program for a model investigation of harbor wave-action problems, it is necessary to select dimensions and directions for the test waves that will allow a realistic test of proposed improvement plans

and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, and the water distance (fetch) over which the wind blows. Selection of test-wave conditions entails evaluation of such factors as:

a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can attack the problem area.

b. The frequency of occurrence and duration of storm winds from the different directions.

c. The alignment, size, and relative geographic position of the navigation entrance to the harbor.

d. The alignment, lengths, and locations of the various reflecting surfaces inside the harbor.

e. The refraction of waves caused by differentials in depth in the area bayward of the harbor, which may create either a concentration or a diffusion of wave energy at the harbor site.

Wave refraction

24. When wind waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations, with respect to the selection of test wave characteristics, are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. The change in wave height and direction can be determined by conducting a wave refraction analysis. The shoaling coefficient, a function of wavelength and water depth, can be obtained from USACERC (1977). Thus the refraction coefficient multiplied by the shoaling coefficient gives a conversion factor for transfer of deepwater wave heights to shallow-water values.

25. Due to the limited fetch in San Francisco Bay, a wave-refraction analysis was not conducted for the Fisherman's Wharf site. The magnitude and direction of winds approaching the area from over the bay were considered to be the governing factors and all waves were assumed to be locally generated. For this study, critical directions of wave approach were determined to be northeast, north-northeast, north, north-northwest, northwest, and west-northwest.

Selection of test waves

26. Long-term measured prototype wave data on which a comprehensive statistical analysis of wave conditions could be based were unavailable for the Fisherman's Wharf area. However, statistical wave hindcast data representative of this area were obtained by the application of hindcasting techniques from USACERC (1977) and Vincent and Lockhart (1983) to wind data acquired at the Oakland Airport and the Alameda Naval Air Station. Model test waves initially selected from these data by SPL are shown in the following tabulation:

Direction	Wave Period sec	Wave Height ft
Northeast	3.0*	2.0*
	3.9	3.3
North-northeast	3.2*	2.5*
	4.9	5.8
North	3.0*	2.0*
	3.7	3.8
North-northwest	3.0*	2.0*
	3.6	3.8
Northwest	3.0*	2.0*
	3.7	3.5
West-northwest	3.0*	2.0*
	3.6	3.4

* Likely significant waves where 95 percent of the waves are smaller and 5 percent are larger. Others are maximum significant wave heights ($H_{1/3}$).

Due to limitations of the model wave generator, however, it was necessary to select wave periods of 3.6 sec and above. Therefore the 3- and 3.2-sec wave periods in the above tabulation were not generated in the model but were replaced with 3.6-sec periods.

27. Prototype wave gages installed in the Fisherman's Wharf area in 1983 indicated that wave periods ranging from 8 to 12 sec and wave heights between 1.5 and 2 ft were experienced at Hyde Street Pier. Consequently, 10-sec, 2-ft waves were also selected for testing in the model from the west-northwest direction (waves approaching from the Golden Gate).

28. During the course of the model investigation, SPL requested that the following additional waves be included in the testing program.

Direction	Wave Period sec	Wave Height ft
North-northeast	4.2	4.8
North	3.6	3.1
North-northwest	3.6	3.3
Northwest	3.8	4.1
West-northwest	10.0	2.5
	10.0	3.0

Analysis of model data

29. Relative merits of the various plans tested were evaluated by:

a. Comparison of wave heights at selected locations in the model.

b. Comparison of sediment tracer movement (erosion and accretion).

c. Visual observations and wave-pattern photographs.

In the wave-height data analysis, the average height of the highest one-third of the waves recorded at each gage location ($H_{1/3}$) was computed. All wave heights were then adjusted to compensate for excessive model wave-height attenuation due to viscous bottom friction by application of Keulegan's equation (Keulegan 1950). From this equation, reduction of wave heights in the model (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel.

Description of Tests

Existing conditions

30. Prior to testing of the various improvement plans, tests were conducted for existing conditions (Plate 1). Wave heights, sediment tracer patterns, and wave-pattern photographs were obtained for test waves from the six tests directions.

Improvement plans

31. Wave-height tests were conducted for 90 test-plan variations. These variations consisted of changes in the lengths, alignments, and locations of the proposed solid, baffled, and/or segmented breakwater structures. Wave-pattern photographs were obtained for all the test plans, while sediment tracer patterns were secured for the most promising outer breakwater plan. Brief descriptions of the improvement plans are presented in the following

subparagraphs; dimensional details are presented in Plates 2-34.

a. Plan 1 (Plate 2) consisted of a 1,450-ft-long curved solid breakwater with a 10-ft-wide cap enclosing the area between Hyde Street Pier and Pier 45. A 385-ft-long baffled breakwater was also attached to the center of Pier 45 at its bayward end on the east side of the west finger. This baffled structure extended to an elevation of -14 ft.

b. Plan 2 (Plate 2) entailed the elements of Plan 1 with a 100-ft extension of the solid breakwater at its western end resulting in a 1,550-ft-long structure.

c. Plan 3 (Plate 2) included the elements of Plan 1 with a 200-ft extension of the solid breakwater at its western end resulting in a 1,650-ft-long structure.

d. Plan 4 (Plate 2) encompassed the elements of Plan 1 with a 300-ft extension of the solid breakwater at its western end resulting in a 1,750-ft-long structure.

e. Plan 5 (Plate 2) entailed the elements of Plan 1 with 100 ft removed from the western end of the solid breakwater resulting in a 1,350-ft-long structure.

f. Plan 6 (Plate 3) consisted of the elements of Plan 1 with a 100-ft extension of the solid breakwater at its eastern end resulting in a 1,550-ft-long structure.

g. Plan 7 (Plate 3) involved the elements of Plan 1 with a 200-ft extension of the solid breakwater at its eastern end resulting in a 1,650-ft-long structure.

h. Plan 8 (Plate 3) involved the elements of Plan 1 with a 300-ft extension of the solid breakwater at its eastern end resulting in a 1,750-ft-long structure.

i. Plan 9 (Plate 3) involved the elements of Plan 1 with a 400-ft extension of the solid breakwater at its eastern end resulting in a 1,850-ft-long structure.

j. Plan 10 (Plate 3) encompassed the 400-ft eastward extension of the solid breakwater (Plan 9), but the 385-ft-long baffled breakwater at the center of Pier 45 on the east side of the west finger was removed.

k. Plan 11 (Plate 4) consisted of a 400-ft eastward extension of the solid breakwater with a 385-ft-long baffled breakwater attached to the eastern side of the east finger of Pier 45 at its bayward end.

l. Plan 12 (Plate 4) entailed the elements of Plan 11 with an additional 215-ft-long baffled breakwater attached to the center of Pier 45 on the east side of the west finger about 170 ft from its bayward end.

m. Plan 13 (Plate 4) included the elements of Plan 11 with a 385-ft-long baffled breakwater attached to the center of Pier 45 on the east side of the west finger at its bayward end.

n. Plan 14 (Plate 5) involved the 1,850-ft-long solid breakwater and the 385-ft-long baffled breakwater of Plan 9 with an additional 200-ft-long baffled breakwater attached to the east side of the east finger on Pier 45.

o. Plan 15 (Plate 5) encompassed the elements of Plan 14 with a 300-ft extension of the solid breakwater at its western end resulting in a 2,150-ft-long structure.

p. Plan 16 (Plate 5) consisted of the elements of Plan 14 with 100 ft removed from the eastern end of the solid breakwater resulting in a 1,750-ft-long structure.

q. Plan 17 (Plate 6) entailed the 1,750-ft-long solid breakwater and the 385-ft-long baffled breakwater of Plan 8 with an additional 385-ft-long solid breakwater installed on the eastern side of Pier 45 resulting in a 200-ft-wide entrance opening.

r. Plan 18 (Plate 6) included the elements of Plan 17 but the 385-ft-long baffled breakwater at the center of Pier 45 attached to the east side of the west finger was removed.

s. Plan 19 (Plate 6) involved the elements of Plan 17 with the shoreward 215-ft section of the baffled breakwater removed from the east side of the west finger of Pier 45.

t. Plan 20 (Plate 7) encompassed the elements of Plan 19, but the shoreward 200-ft section of the solid breakwater installed on the eastern side of Pier 45 was replaced with a baffled breakwater section.

u. Plan 21 (Plate 8) consisted of a 1,385-ft-long curved solid breakwater with a 6-ft-wide cap enclosing the area between Hyde Street Pier and Pier 45. The entrance opening at Pier 45 was 165 ft wide.

v. Plan 22 (Plate 8) involved the elements of Plan 21 with a 100-ft extension of the breakwater at its western end resulting in a 1,485-ft-long structure.

w. Plan 23 (Plate 8) entailed the elements of Plan 21 with a 200-ft extension of the breakwater at its western end resulting in a 1,585-ft-long structure.

x. Plan 24 (Plate 8) included the elements of Plan 21 with a 300-ft extension of the breakwater at its western end resulting in a 1,685-ft-long structure

y. Plan 25 (Plate 9) consisted of the 1,685-ft-long breakwater of Plan 24 with a 200-ft-long solid breakwater attached to Municipal Pier approximately 200 ft from its bayward end.

z. Plan 26 (Plate 9) included the elements of Plan 25, but the 200-ft-long breakwater attached to Municipal Pier was extended shoreward 200 ft resulting in a 400-ft-long structure.

aa. Plan 27 (Plate 9) entailed the elements of Plan 26, but the 400-ft-long breakwater attached to Municipal Pier was extended bayward 200 ft resulting in a 600-ft-long structure.

bb. Plan 28 (Plate 9) involved the elements of Plan 27, but the 600-ft-long breakwater attached to Municipal Pier was extended shoreward 200 ft resulting in an 800-ft-long structure.

cc. Plan 29 (Plate 10) encompassed the elements of Plan 28, but the 800-ft-long breakwater attached to Municipal Pier was extended shoreward 200 ft resulting in a 1,000-ft-long structure.

dd. Plan 30 (Plate 10) included the elements of Plan 29, but the 1,000-ft-long breakwater attached to Municipal Pier was reduced by 200 ft at its bayward end resulting in an 800-ft-long structure.

ee. Plan 31 (Plate 10) entailed the elements of Plan 30, but the 800-ft-long breakwater attached to Municipal Pier was reduced by 200 ft at its bayward end resulting in a 600-ft-long structure.

ff. Plan 32 (Plate 10) involved the elements of Plan 31, but the 600-ft-long breakwater attached to Municipal Pier was extended 100 ft bayward resulting in a 700-ft-long structure.

gg. Plan 33 (Plate 10) encompassed the elements of Plan 32, but the solid breakwater enclosing the Fisherman's Wharf area was reduced in length by 100 ft at its western end resulting in a 1,585-ft-long structure.

hh. Plan 34 (Plate 11) consisted of the 1,585-ft-long solid breakwater of Plan 23 and a 385-ft-long baffled breakwater attached to the eastern side of the east finger of Pier 45 at its bayward end.

ii. Plan 35 (Plate 11) entailed the elements of Plan 34 with an additional 185-ft-long baffled breakwater attached to the center of Pier 45 on the east side of the west finger at its bayward end.

jj. Plan 36 (Plate 11) involved the elements of Plan 23 with a 185-ft-long baffled breakwater attached to the center of Pier 45 (east side of west finger) and a 200-ft-long baffled breakwater attached to the eastern side of Pier 45 (east side of east finger).

kk. Plan 37 (Plate 12) encompassed the 1,585-ft-long solid breakwater of Plan 23 with a 385-ft-long baffled breakwater attached to the center of Pier 45 on the east side of the west finger and a 385-ft-long baffled breakwater attached to the east side of the east finger of Pier 45.

ll. Plan 38 (Plates 12 and 13) include the elements of Plan 23 with a 385-ft-long baffled breakwater attached to the center of Pier 45 on the east side of the west finger and a 200-ft-long baffled breakwater attached to the east side of the east finger of Pier 45.

mm. Plan 39 (Plates 12 and 13) entailed the elements of Plan 23 with a 385-ft-long baffled breakwater attached to the center of Pier 45 on the east side of the west finger at its bayward end.

nn. Plan 40 (Plate 14) encompassed the 1,685-ft-long solid breakwater of Plan 24 with a 385-ft-long baffled breakwater attached to the center of Pier 45 on the east side of the west finger and a 200-ft-long baffled breakwater attached to the east side of the east finger of Pier 45.

oo. Plan 41 (Plate 15) included the 1,585-ft-long solid breakwater of Plan 23 with a 180-ft-long baffled breakwater attached to the west side of the east finger and a 150-ft-long baffled breakwater attached to the west side of the west finger of Pier 45 at its bayward end.

pp. Plan 42 (Plate 15) involved the 1,585-ft-long solid breakwater of Plan 23 with a 180-ft-long baffled breakwater attached to the west side of the east finger of Pier 45.

qq. Plan 43 (Plate 15) consisted of the 1,585-ft-long solid breakwater of Plan 23 with a 150-ft-long baffled breakwater attached to the west side of the west finger of Pier 45.

rr. Plan 44 (Plate 16) encompassed the 1,585-ft-long solid breakwater of Plan 23 with a 180-ft-long baffled breakwater attached to the west side of the east finger and a 158-ft-long baffled breakwater attached to the east side of the west finger of Pier 45.

ss. Plan 45 (Plate 16) entailed the 1,585-ft-long solid breakwater of Plan 23 with a 500-ft-long baffled breakwater attached to the western side of the west finger of Pier 45.

tt. Plan 46 (Plate 17) included the 1,585-ft-long solid breakwater of Plan 23 with a 220-ft-long baffled breakwater attached diagonally between the fingers of Pier 45.

uu. Plan 47 (Plate 17) involved the 1,585-ft-long solid breakwater of Plan 23 with a 400-ft-long baffled breakwater attached to the western side of the west finger of Pier 45.

vv. Plan 48 (Plate 18) encompassed the 1,585-ft-long solid breakwater of Plan 23 with a 200-ft-long baffled breakwater and a 180-ft-long baffled breakwater attached to the east and west sides, respectively, on the east finger of Pier 45.

ww. Plan 49 (Plate 18) consisted of the 1,585-ft-long solid breakwater of Plan 23 with a 200-ft-long baffled breakwater attached to the east side of the east finger, a 180-ft-long baffled breakwater attached to the west side of the east finger, and a 150-ft-long baffled breakwater attached to the west side of the west finger of Pier 45.

xx. Plan 50 (Plate 19) included the 1,585-ft-long solid breakwater of Plan 23 with a 200-ft-long baffled breakwater attached to the east side of the east finger and a 500-ft-long baffled breakwater attached to the west side of the west finger of Pier 45.

yy. Plan 51 (Plate 19) involved the 1,585-ft-long solid breakwater of Plan 23 with a 200-ft-long baffled breakwater attached to the east side of the east finger and a 220-ft-long baffled breakwater attached diagonally between the fingers of Pier 45.

zz. Plan 52 (Plate 20) consisted of the 1,585-ft-long solid breakwater of Plan 23 with a 180-ft-long segmented breakwater (30-ft solid sections, 4-ft openings) installed adjacent to the west side of the east finger of Pier 45.

aaa. Plan 53 (Plate 20) entailed the 1,585-ft-long solid breakwater of Plan 23 with 180-ft-long and 150-ft-long segmented breakwaters (30-ft solid sections, 4-ft openings) installed adjacent to the west sides of the east and west fingers, respectively, of Pier 45.

bbb. Plan 54 (Plate 21) encompassed the 1,585-ft-long solid breakwater of Plan 23 with a 500-ft-long segmented breakwater (30-ft solid sections, 4-ft openings) installed adjacent to the west side of the west finger of Pier 45.

ccc. Plan 55 (Plate 21) included the 1,585-ft-long solid breakwater of Plan 23 with a 220-ft-long segmented breakwater (30-ft solid sections, 4-ft openings) installed diagonally between the fingers of Pier 45.

ddd. Plan 56 (Plate 22) entailed the 1,585-ft-long solid breakwater of Plan 23 with 200-ft-long and 180-ft-long segmented breakwaters (30-ft solid sections, 4-ft openings) installed adjacent to the east and west sides, respectively, of the east finger of Pier 45.

eee. Plan 57 (Plate 22) involved the 1,585-ft-long solid breakwater of Plan 23 with 200-ft-long and 180-ft-long segmented breakwaters (30-ft solid sections, 4-ft openings) installed adjacent to the east and west sides, respectively, of the east finger of Pier 45 and a 150-ft-long segmented breakwater (30-ft solid sections, 4-ft openings) installed adjacent to the west side of the west finger of Pier 45.

fff. Plan 58 (Plate 23) consisted of the 1,585-ft-long solid breakwater of Plan 23 with 200-ft-long and 500-ft-long segmented breakwaters (30-ft solid sections, 4-ft openings) installed adjacent to the east side of the east finger and the west side of the west finger, respectively, of Pier 45.

ggg. Plan 59 (Plate 23) entailed the 1,585-ft-long solid breakwater of Plan 23 with a 200-ft-long segmented breakwater (30-ft solid sections, 4-ft openings) installed adjacent to the east side of the east finger and a 220-ft-long segmented breakwater (30-ft solid sections, 4-ft openings) installed diagonally between the fingers of Pier 45.

hhh. Plan 60 (Plate 24) included the 1,585-ft-long solid breakwater of Plan 23 with a 200-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger and a 500-ft-long segmented breakwater (30-ft solid sections, 4-ft openings) installed adjacent to the west side of the west finger of Pier 45.

iii. Plan 61 (Plate 24) encompassed the 1,585-ft-long solid breakwater of Plan 23 with 200-ft-long and 500-ft-long segmented breakwaters (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger and the west side of the west finger, respectively, of Pier 45.

jjj. Plan 62 (Plate 24) involved the 1,585-ft-long solid breakwater of Plan 23 with a 500-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45.

kkk. Plan 63 (Plate 25) consisted of the 1,585-ft-long solid breakwater of Plan 23 with a 200-ft-long solid breakwater installed adjacent to the east side of the east finger and a 500-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45.

lll. Plan 64 (Plate 26) consisted of the elements of Plan 63 with 100 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,485-ft-long structure.

mmm. Plan 65 (Plate 26) entailed the elements of Plan 63 with 200 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,385-ft-long structure.

nnn. Plan 66 (Plate 26) involved the elements of Plan 63 with 260 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,325-ft-long structure.

ooo. Plan 67 (Plate 27) included the elements of Plan 62 with 100 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,485-ft-long structure.

ppp. Plan 68 (Plate 27) encompassed the elements of Plan 62 with 200 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,385-ft-long structure.

qqq. Plan 69 (Plate 27) entailed the elements of Plan 62 with 260 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,325-ft-long structure.

rrr. Plan 70 (Plate 28) included the elements of Plan 54 with 100 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,485-ft-long structure.

sss. Plan 71 (Plate 28) involved the elements of Plan 54 with 200 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,385-ft-long structure.

ttt. Plan 72 (Plate 28) consisted of the elements of Plan 54 with 260 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,325-ft-long structure.

uuu. Plan 73 (Plate 29) entailed the elements of Plan 58 with 100 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,485-ft-long structure.

vvv. Plan 74 (Plate 29) encompassed the elements of Plan 58 with 200 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,385-ft-long structure.

www. Plan 75 (Plate 29) included the elements of Plan 58 with 260 ft of structure removed from the eastern end of the outer breakwater resulting in a 1,325-ft-long structure.

xxx. Plan 76 (Plate 30) involved a reorientation and slight reduction in length of the 1,585-ft-long solid breakwater of Plan 23. The eastern end of the structure was shifted approximately 40 ft bayward along the fender line of Pier 45 which resulted in a length reduction of the structure of approximately 25 ft. The plan also included a 150-ft-long diagonal segmented breakwater (28-ft solid sections, 6-ft openings) between the fingers of Pier 45. The entrance opening remained at 165 ft. In addition, a 500-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) was also installed adjacent to the west side of the west finger of Pier 45.

yyy. Plan 77 (Plate 30) consisted of the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 350-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45.

zzz. Plan 78 (Plate 30) included the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 250-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45.

aaaa. Plan 79 (Plate 31) encompassed the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 150-ft-long and a 100-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45.

bbbb. Plan 80 (Plate 31) entailed the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 150-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45.

cccc. Plan 81 (Plate 31) involved the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 only, with no additional structures installed.

dddd. Plan 82 (Plate 32) consisted of the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 500-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45 and a 200-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger of Pier 45.

eeee. Plan 83 (Plate 32) entailed the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 350-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45 and a 200-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger of Pier 45.

ffff. Plan 84 (Plate 32) involved the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 250-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45 and a 200-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger of Pier 45.

gggg. Plan 85 (Plate 32) included the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 100-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45 and a 200-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger of Pier 45.

hhhh. Plan 86 (Plate 33) encompassed the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76 with a 360-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger of Pier 45. This segmented breakwater extended bayward from the pier along the fender line for a distance of 160 ft and resulted in a 165-ft-wide entrance opening between its bayward end and the solid outer breakwater.

iiii. Plan 87 (Plate 33) consisted of the 1,560-ft-long solid breakwater of Plan 76 with a 360-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the east side of the east finger of Pier 45. This segmented breakwater extended bayward from the pier along the fender line for a distance of 160 ft and resulted in a 165-ft-wide entrance opening between its bayward end and the solid outer breakwater.

jjjj. Plan 88 (Plate 34) involved the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76. The bayward end of this diagonal segmented breakwater was reoriented approximately 40 ft in an easterly direction. Also included was a 500-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) installed adjacent to the west side of the west finger of Pier 45.

kkkk. Plan 89 (Plate 34) entailed the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76. The bayward end of this diagonal segmented breakwater was reoriented approximately 40 ft in an easterly direction. A 350-ft-long segmented breakwater (28-ft solid sections, 6-ft openings) was also installed adjacent to the west side of the west finger of Pier 45.

llll. Plan 90 (Plate 34) included the 1,560-ft-long solid breakwater and 150-ft-long diagonal segmented breakwater of Plan 76, but the bayward end of this segmented breakwater was reoriented approximately 40 ft in an easterly direction.

Wave-height tests

32. Wave-height tests for the various improvement plans were conducted using test waves from one or more of the directions listed in paragraph 26. Tests involving certain proposed improvement plans were limited to the most critical direction of wave approach (i.e. northeast and west-northwest). The most promising initial plan of improvement (Plan 38) was tested comprehensively for waves from all six test directions. The improvement plan involving the best configuration at the east entrance (Plan 78) was tested for waves from northeast, north-northeast, and north. Wave gage locations for each improvement plan are shown in Plates 2-34. Wave-height criteria of 1.5 ft in the historical vessel mooring area (gages 6-9) and 1.0 ft in the proposed small-craft mooring area (gages 3-5) and existing fishing vessel mooring area (gages 11 and 12, 14 and 15) were established by SPL.

Sediment tracer tests

33. Sediment tracer tests were limited to only the most promising outer breakwater plan (Plan 38) using test waves for all six test directions with both the 0.0- and +5.7 ft swl's. Tracer material was introduced into the model at five locations along the beach in the Aquatic Park area prior to being subjected to the various test waves.

Videotape

34. Videotape footage of the Fisherman's Wharf area model was secured for existing conditions and Plan 38 showing the area under attack by storm waves approaching from northeast, north-northeast, and west-northwest test directions. Videotape footage for Plan 78 was also obtained for test waves from northeast. This footage was furnished to SPL and SPN for use in briefings, public meetings, etc.

Test Results

35. In evaluating test results, the relative merits of various plans were based on an analysis of measured wave heights in the mooring areas and entrance. Model wave heights (significant wave height or $H_{1/3}$) were tabulated to show measured values at selected locations. The general movement of tracer material and subsequent deposits along the Aquatic Park beach were shown in photographs. Arrows were superimposed onto these photographs to depict sediment movement patterns.

Existing conditions

36. Results of wave-height tests conducted for existing conditions are presented in Table 1. Maximum wave heights with the 0.0-ft swl were 4.8 ft in the proposed small-craft mooring area (gage 3) for 4.9-sec, 5.8-ft test waves from north-northeast; 4.8 ft along Hyde Street Pier in the historical fleet mooring area (gage 7) for 3.7-sec, 3.8-ft test waves from north; and 3.5 ft in the existing fishing vessel mooring area (gage 11) for 3.6-sec, 3.8-ft test waves from north-northwest. For the +5.7 ft swl, maximum wave heights were 4.4 ft in the proposed small-craft mooring area (gages 3 and 4) for 4.9-sec, 5.8-ft test waves from north-northeast and 3.7-sec, 3.8-ft test waves from north; 5.5 ft in the historical vessel mooring area (gage 8) for 4.9-sec. 5.8-ft test waves from north-northeast; and 2.7 ft in the fishing vessel mooring area (gages 11 and 15) for 10-sec, 3-ft test waves from west-northwest and 3.8-sec, 4.1-ft test waves from northwest. Typical wave patterns for existing conditions are shown in Photos 1-14.

37. The general movement of tracer material and subsequent deposits for representative waves for existing conditions are shown in Photos 15-30 for the six tests directions and two swl's. The general movement of tracer material in Aquatic Park was from east to west, in most instances, for test waves approaching from northeast, north-northeast, north, and north-northwest using both the 0.0- and +5.7 ft swl's. In some cases, sediment tracer material in a particular area did not move; and in other instances, it migrated shoreward with some material subsequently moving westerly and some easterly. For test waves from northwest and west-northwest, tracer material in Aquatic Park generally moved from west to east for both the 0.0- and +5.7 ft swl's. Again, in some locations the material did not move, and in some instances material moved shoreward initially and eventually migrated to both the east and the west. The smaller test waves (2.0- and 2.5-ft waves) from the various directions resulted in negligible movement of sediment in the Aquatic Park area.

Improvement plans

38. Wave-height measurements obtained for the original test plan (Plan 1) for test waves from the various directions are presented in Table 2. For the 0.0-ft swl, maximum wave heights were 4.7 ft in the proposed small-craft mooring area (gage 3) for 3.9-sec, 3.3-ft test waves from northeast; 3.4 ft in the historical vessel mooring area (gage 8) for 4.9-sec, 5.8-ft test waves from north-northeast; and 1.2 ft in the existing fishing vessel mooring

area (gage 15) for 4.9-sec, 5.8-ft test waves from north-northeast. For the +5.7 ft swl, maximum wave heights were 4.3 ft in the proposed small-craft mooring area (gage 3) for 3.9-sec, 3.3-ft test waves from northeast; 3.7 ft in the historical vessel mooring area (gage 8) for 4.9-sec, 5.8-ft test waves from north-northeast; and 1.2 ft in the existing fishing vessel mooring area (gage 11) for 4.9-sec, 5.8-ft test waves from north-northeast. Visual observations indicated substantial wave energy entering the harbor through the 200-ft-wide entrance at Pier 45. Typical wave patterns for Plan 1 for test waves from northeast and west-northwest are shown in Photos 31 and 32.

39. Wave heights secured for test plans involving modifications to the western end of the solid breakwater (Plans 2-5) for 10-sec, 2-ft test waves from west-northwest with the +5.7 ft swl are presented in Table 3. Maximum wave heights obtained in the proposed small-craft mooring area were 1.2, 1.1, 0.8, and 1.2 ft for Plans 2-5, respectively. Only Plan 4 (300-ft breakwater extension) met the established wave-height criterion of 1.0 ft in the proposed small-craft mooring area. Plan 3 (200-ft breakwater extension) exceeded the criterion only by 0.1 ft, however. Maximum wave heights in the historical vessel mooring area were 1.4, 1.3, 1.0, and 1.6 ft, respectively, for Plans 2-5. Plans 2-4 (100-, 200-, and 300-ft breakwater extensions) met the 1.5-ft wave-height criterion in this area, and Plan 5 (100-ft breakwater reduction) exceeded the criterion by only 0.1 ft. Maximum wave heights obtained in the existing fishing vessel mooring area were 1.0, 1.0, 0.8, and 1.0 ft for Plans 2-5, respectively. The 1.0-ft wave-height criterion in this area was met by all the test plans. Wave-pattern photographs obtained for Plans 2-5 for test waves from west-northwest are shown in Photos 33-36.

40. Results of wave-height tests for Plans 6-10 for 3.9-sec, 3.3-ft test waves from northeast with the +5.7 ft swl are presented in Table 4. Maximum wave heights obtained in the proposed small-craft mooring area were 4.1, 1.8, 1.3, 1.2, and 2.4 ft, respectively, for Plans 6-10. None of the test plans met the established 1.0-ft wave-height criterion in the small-craft mooring area. Maximum wave heights were 2.3, 1.3, 1.2, 1.0, and 2.1 ft in the historical vessel mooring area and 0.5, 0.5, 0.3, 0.2, and 0.2 ft in the existing fishing vessel mooring area for Plans 6-10, respectively. The 1.5-ft wave-height criterion in the historical mooring area was met by Plans 7-9, and the 1.0-ft wave-height criterion in the fishing vessel mooring area was met by Plans 6-10. Wave patterns secured for Plans 6-10 for test waves from northeast are shown in Photos 37-41.

41. Wave heights obtained for Plans 11-20 for 3.9-sec, 3.3-ft test waves from northeast with the +5.7 ft swl are presented in Table 5. Maximum wave heights in the proposed small-craft mooring area were 1.8, 1.2, 1.0, 0.7, 1.0, 1.2, 0.7, 1.4, 1.0, and 1.1 ft for Plans 11-20. respectively. The 1.0-ft wave-height criterion was met with the baffled breakwater sections of Plans 13, 14, and 15 attached to Pier 45 and the combined solid and baffled breakwater sections of Plans 17 and 19 attached to Pier 45. Only the baffled breakwater section of Plan 11 exceeded the 1.5-ft wave-height criterion in the historical vessel mooring area. Plans 11-20 were all well within the established 1.0-ft wave-height criterion in the existing fishing vessel mooring area. Wave patterns obtained for Plans 11-20 for test waves from northeast are shown in Photos 42-51.

42. Results of wave-height tests for representative test waves from west-northwest with Plans 21-33 installed are presented in Table 6 for the +5.7 ft swl. For 10-sec, 2-ft test waves, the original breakwater configuration (Plan 21) resulted in maximum wave heights of 1.3 ft in the proposed small-craft mooring area, 2.1 ft in the historical vessel mooring area, and 1.0 ft in the existing fishing vessel mooring area. The 100- and 200-ft extensions in length of the western portion of the breakwater (Plans 22 and 23) resulted in maximum wave heights of 1.1 and 1.0 ft in the proposed small-craft mooring area, 1.8 and 1.5 ft in the historical vessel mooring area, and 0.6 and 0.5 ft in the existing fishing vessel mooring area. The 200-ft extension (Plan 23) of the original breakwater configuration (Plan 21) satisfied the wave-height criteria in the harbor for 10-sec, 2-ft test waves. The western end of the structure terminated 100 ft bayward of the original (Plan 1) breakwater configuration. At this point in the model investigation, SPL requested that additional tests be conducted to determine the protection required for 10-sec, 3-ft test waves. For these test waves, maximum wave heights in the proposed small-craft mooring area were 1.8, 1.7, 1.1, 1.1, 1.1, 1.2, 1.0, 0.9, 1.1, 0.9, and 1.1 ft for Plans 23-33, respectively. A minimum of 700 ft of solid breakwater attached to Municipal Pier (Plan 32) was required to reduce wave heights within the desired criterion. Plans 28-33 met the 1.5-ft criterion in the historical vessel mooring area and Plans 21-33 met the 1.0-ft criterion in the existing fishing vessel mooring area. Typical wave patterns for Plans 21-33 for test waves from west-northwest are shown in Photos 52-64.

43. Wave-height test results obtained for Plan 23 and Plans 34-39 for

3.9-sec. 3.3-ft test waves from northeast are presented in Table 7. With no baffled breakwaters installed at Pier 45 (Plan 23), maximum wave heights were 2.2 ft in the proposed small-craft harbor mooring area, 3.1 ft in the historical vessel mooring area, and 0.3 ft in the existing fishing vessel mooring area with the +5.7 ft swl. Maximum wave heights for the +5.7 ft swl with various baffled breakwater sections attached to Pier 45 were 2.5, 1.3, 1.9, 1.1, 1.0, and 1.0 ft in the proposed small-craft mooring area; 2.4, 1.5, 1.8, 1.6, 1.5, and 1.4 ft in the historical vessel mooring area; and 0.2, 0.3, 0.4, 0.3, 0.3, and 0.4 ft in the existing fishing vessel mooring area for Plans 34-39, respectively. Typical wave patterns for Plan 23 and Plans 34-39 for test waves from northeast are shown in Photos 65-71. Plans 38 and 39 met the established wave-height criteria within the harbor for the +5.7 ft swl and were exposed to test waves with the 0.0-ft swl. Plan 38 met the criteria for these tests conditions and was subjected to comprehensive testing.

44. Results of wave-height tests conducted for plan 38 for test waves from the six directions are shown in Table 8. For the 0.0-ft swl, maximum wave heights were 1.0 ft in the proposed small-craft mooring area (gages 3 and 4) for 3.6-sec, 3.3-ft test waves form north-northwest and 3.8-sec, 4.1-ft test waves from northwest; 1.2 ft in the historical vessel mooring area (gage 7) for 3.9-sec, 3.3-ft test waves from northeast; and 1.1 ft in the existing fishing boat mooring area (gage 11) for 10-sec, 2.5- and 3-ft test waves from west-northwest. For the +5.7 ft swl, maximum wave heights were 1.8 ft in the proposed small-craft mooring area (gage 3) for 10-sec, 3-ft waves from west-northwest; 2.2 ft in the historical vessel mooring area (gage 8) for 10-sec, 3-ft test waves from west-northwest; and 0.6 ft in the existing fishing vessel mooring area (gages 12 and 15) for 3.6-sec, 3.1-ft test waves from north and 10-sec, 3-ft test waves from west-northwest. The established wave-height criteria within the harbor were satisfied for all test waves with the exception of 10-sec, 2.5- and 3-ft waves from west-northwest. Typical wave patterns for Plan 38 for test waves from the various directions are shown in Photos 72-84.

45. The western end of the Plan 38 solid breakwater was extended shoreward by 100 ft (Plan 40) and subjected to 10-sec, 2.5-ft test waves from west-northwest. Wave heights obtained for Plan 40 are presented in Table 9 for the 0.0- and +5.7 ft swl's. Maximum wave heights of 1.4 ft in the small-craft mooring area occurred with the +5.7 ft swl, 1.8 ft in the historical vessel mooring area occurred with the +5.7 ft swl, and 1.0 ft in the existing

fishing vessel mooring area occurred with the 0.0-ft swl. The 100-ft breakwater extension of Plan 40 was ineffective in further reducing wave heights within the harbor as opposed to those obtained for Plan 38. Wave patterns with Plan 40 installed are shown in Photo 85.

46. Evaluation of test data to this point indicated that Plan 38 was optimum with regard to wave heights within the harbor. The established wave-height criteria was met by all test waves except 10-sec, 2.5- and 3-ft test waves from west-northwest. The recurrence interval for these swell conditions from the Golden Gate would probably be about 50 years, or greater. Considering this frequency of occurrence, the Plan 38 breakwater configuration was selected for additional testing.

47. The general movement of tracer material and subsequent deposits for representative test waves for Plan 38 for the six directions and two swl's are shown in Photos 86-101. Due to the protection provided by the offshore breakwater, shoreline sediment in Aquatic Park for test waves from northeast, north-northeast, north, and north-northwest did not move in some cases; and in other instances the sediment migrated only shoreward with some material subsequently moving to the east and some to the west. Predominant movement to either the east or the west was not apparent for these test directions. For test waves from northwest and west-northwest, particularly with the +5.7 ft swl, sediment tracer material, in general, had a tendency to migrate in an easterly direction.

48. During the conduct of testing, visual observations indicated standing-wave patterns in the entrance caused by reflections off the baffled breakwaters at Pier 45, particularly for test waves from northeast. To determine wave heights in the entrance bayward of Pier 45, the alternate wave gage locations (shown in Plate 13) were installed in the model, and wave-height tests were conducted. Results of these tests for Plans 38 and 39 are presented in Table 10 for test waves from northeast. For the 0.0-ft swl, maximum wave heights in the entrance channel (gage 3A) were 8.8 and 8.4 ft, respectively, for Plans 38 and 39. With the +5.7 ft swl, maximum wave heights in the entrance were 9.2 and 9.1 ft for Plans 38 and 39, respectively.

49. In an effort to reduce wave heights in the entrance, additional baffled breakwater configurations at Pier 45 were tested. Results of the wave-height tests for Plans 41-46 for 3.9-sec, 3.3-ft test waves from northeast are presented in Table 11. With the 0.0-ft swl, maximum wave heights in the

entrance (gages 1A, 2A, or 3A) were 4.5, 3.3, 3.6, 5.3, 4.2, and 4.4 ft for Plans 41-46, respectively. For the +5.7 ft swl, maximum wave heights of 4.5, 3.8, 4.1, 4.8, 4.1, and 3.7 ft were recorded in the entrance for Plans 41-46, respectively. Test waves for Plans 42-44 resulted in wave heights in the proposed small-craft mooring area that exceeded the established 1.0-ft wave-height criterion. Wave heights in other areas in the harbor were within the specified criteria. Typical wave patterns for Plans 41-46 for test waves from northeast are shown in Photos 102-107.

50. Wave heights obtained with Plans 41 and 45-51 installed for 4.2-sec, 4.8-ft test waves from north-northeast are presented in Table 12. For the 0.0-ft swl, maximum wave heights in the entrance were 5.2, 4.9, 4.7, 4.7, 4.7, 5.1, 5.1, and 4.1 ft for Plans 41 and 45-51, respectively. With the +5.7 ft swl, maximum wave heights in the entrance were 4.3, 5.1, 3.2, 4.1, 3.5, 3.6, 4.2, and 3.1 ft, respectively, for Plans 41 and 45-51. Test results indicated that Plans 41, 46, and 47 exceeded the 1.0-ft wave-height criterion in the proposed small-craft mooring area. Wave heights in the historical vessel mooring area and the existing fishing vessel mooring area were within the established criteria.

51. Results of wave-height tests for Plans 48-51 for 3.9-sec, 3.3-ft test waves from northeast are presented in Table 13. For the 0.0-ft swl, maximum wave heights in the entrance were 5.4, 3.9, 3.9, and 4.3 ft, respectively, for Plans 48-51. For the +5.7 ft swl, maximum wave heights were 4.1, 3.9, 4.8, and 3.9 ft in the entrance for Plans 48-51, respectively. Only Plan 48 failed to meet the specified 1.0-ft wave-height criterion in the proposed small-craft mooring area, and all the test plans met the criteria in other areas of the harbor. Typical wave patterns for Plans 48-51 are shown in Photos 108-111 for test waves from northeast.

52. At this point in the model investigation, SPL requested that alternatives to the baffled breakwater structures be developed since structural design of these breakwaters was impractical. Testing progressed with various segmented breakwater configurations installed adjacent to various portions of Pier 45.

53. Results of wave-height tests obtained with Plans 52-59 installed in the model are presented in Table 14 for 3.9-sec, 3.3-ft test waves from northeast. Maximum wave heights in the entrance for the 0.0-ft swl were 3.9, 4.5, 4.5, 4.7, 4.0, 4.6, 4.9, and 5.1 ft for Plans 52-59, respectively. For the

+5.7 ft swl, maximum wave heights were 4.3, 3.8, 3.3, 4.1, 4.9, 3.9, 3.4, and 5.4 ft in the entrance, respectively, for Plans 52-59. Plans 52, 55, and 59 resulted in wave heights that exceeded the 1.0-ft criteria in the proposed small-craft mooring area while all the test plans were within the established wave-height criteria in other areas of the harbor. Wave-pattern photographs obtained for Plans 52-59 for test waves from northeast are shown in Photos 112-119.

54. Wave heights obtained for Plans 60-63 for 3.9-sec, 3.3-ft test waves from northeast are presented in Table 15. With 0.0-ft swl, maximum wave heights were 5.9, 5.6, 4.7, and 4.6 ft in the entrance for Plans 60-63, respectively. For the +5.7 ft swl, maximum wave heights in the entrance were 4.5, 4.5, 3.9, and 3.5 ft for Plans 60-63, respectively. The established wave-height criteria in the harbor was met by all the test plans. Typical wave patterns for Plans 60-63 are shown in Photos 120-123 for test waves from northeast.

55. Wave heights secured for Plans 53 and 54, 56-58, and 60-63 for 4.2-sec, 4.8-ft test waves from north-northeast are presented in Table 16. Maximum wave heights in the entrance were 6.0, 5.4, 5.2, 5.1, 4.3, 4.1, 4.8, 4.9, and 4.6 ft with the 0.0-ft swl for Plans 53 and 54, 56-58, and 60-63, respectively. For the +5.7 ft swl, maximum wave heights in the entrance were 4.1, 4.1, 5.1, 4.4, 4.5, 3.5, 4.6, 4.7, and 3.9 ft for Plans 53 and 54, 56-58, and 60-63, respectively. Wave heights for Plans 53, 56, and 57 exceeded the 1.0-ft criterion in the proposed small-craft mooring area, and waves for Plan 56 resulted in heights that exceeded the 1.5-ft criterion in the historical vessel mooring area. All test plans met the 1.0-ft criterion in the existing fishing vessel mooring area.

56. Results of wave-height tests for Plans 64-75 for 4.2-sec, 4.8-ft test waves from north-northeast are presented in Table 17. For the 0.0-ft swl, maximum wave heights in the entrance were 3.4, 3.6, 3.5, 3.9, 5.4, 6.4, 4.1, 5.2, 4.5, 3.9, 4.5, and 4.8 ft for Plans 64-75, respectively. With the +5.7 ft swl, maximum wave heights in the entrance were 3.0, 3.3, 3.3, 2.9, 3.5, 3.5, 3.9, 3.4, 3.1, 4.1, 3.9, and 4.4 ft, respectively, for Plans 64-75. Wave heights obtained for Plans 67, 68, 69, and 75 exceeded the criterion in the proposed small-craft mooring area, and wave heights for Plans 69 and 75 exceeded the criterion in the historical vessel mooring area.

57. Wave-height test results with Plans 64-75 installed for 3.9-sec,

3.3-ft test waves from northeast for the 0.0-ft swl are presented in Table 18. Maximum wave heights obtained in the entrance were 5.8, 4.4, 6.1, 5.7, 4.5, 5.4, 5.7, 6.8, 5.8, 4.8, 5.9, and 5.4 ft for Plans 64-75, respectively. None of the test plans met the required 1.0-ft wave-height criterion in the proposed small-craft mooring area. Plans 66, 67, 69, 71, 72, and 75 resulted in wave heights that exceeded the established 1.5-ft wave-height criterion in the historical vessel mooring area. Typical wave patterns obtained for Plans 64-75 for test waves from northeast are presented in Photos 124-135.

58. Visual observations to this point revealed reflected wave energy off many of the segmented breakwater plans back toward the entrance, particularly for test waves from northeast. A series of visual tests were conducted for numerous breakwater entrance configurations until various test plans that appeared more promising were identified. From this point, wave-height testing proceeded.

59. Results of wave-height tests with Plans 76-90 installed in the model are presented in Table 19 for 3.9-sec, 3.3-ft test waves from northeast with the 0.0-ft swl. Maximum wave heights obtained in the entrance were 4.8, 4.4, 3.9, 4.4, 4.3, 4.0, 4.4, 4.7, 4.3, 5.0, 4.8, 4.1, 5.9, 5.4, and 4.2 ft for Plans 76-90, respectively. Test results revealed that Plans 79, 81, 85, 86, 87, 89, and 90 failed to meet the established 1.0-ft wave-height criterion in the proposed small-craft mooring area. Only Plan 90 did not meet the specified criterion of 1.5 ft in the historical vessel mooring area, and wave heights for all the test plans were well within the 1.0-ft criterion in the fishing vessel mooring area. Typical wave patterns secured for Plans 76-90 for test waves from northeast are shown in Photos 136-150.

60. Wave-height data obtained for Plan 78 for test waves from northeast, north-northeast, and north are presented in Table 20 for the 0.0-and +5.7 ft swl's. For the 0.0-ft swl, maximum wave heights were 1.0 ft in the proposed small-craft mooring area for 4.2-sec, 4.8-ft test waves from north-northeast and 3.6-sec, 3.1-ft test waves from north; 1.3 ft in the historical vessel mooring area for 4.2-sec, 4.8-ft test waves from north-northeast; and 0.4 ft in the existing fishing vessel mooring area for 4.2-sec, 4.8-ft test waves from north-northeast. With the +5.7 ft swl, maximum wave heights were 0.9 ft in the proposed small-craft mooring area, 1.4 ft in the historical vessel mooring area, and 0.5 ft in the existing fishing vessel mooring area, all for 4.2-sec, 4.8-ft test waves from north-northeast. The various wave-height

criteria in the harbor were satisfied for all these test waves. Maximum wave heights in the entrance were 4.5 ft for 4.2-sec, 4.8-ft test waves from north-northeast for both the 0.0- and +5.7 ft swl's. Typical wave patterns secured for Plan 78 for test waves from northeast, north-northeast, and north with the +5.7 ft swl are shown in Photos 151-156.

Discussion of test results

61. Results of wave-height tests for existing conditions indicated rough and turbulent wave conditions in the various mooring areas of the harbor for storm waves from all test directions. The harbor is virtually unprotected with wave heights obtained in excess of 4 ft in the proposed small-craft harbor mooring area, in excess of 3 ft in the existing fishing boat mooring area, and in excess of 5 ft along Hyde Street Pier in the historical vessel mooring area.

62. Sediment movement in Aquatic Park for existing conditions is typical of a pocket beach. Material moved in both directions (east and west) depending on the incident wave direction with no material leaving the system. A major factor in determining the net movement of material to either the east or west would be the frequency of occurrence of storm waves from the various directions. Another consideration in the Aquatic Park area, in regard to net sediment transport, would be the protection provided by the historic fleet moored adjacent to Hyde Street Pier. These vessels (which were not simulated in the model) may provide some protection to the beach for waves from the easterly directions and impede the movement of sediment to the west. Model tests indicated that the more significant sediment movement occurred for very severe locally generated storm wave conditions within the bay and for swell conditions through the Golden Gate. The lesser storm wave conditions (2.0- to 2.5-ft test waves) resulted in only minimal movement of sediment tracer material.

63. Results of wave-height tests for the initial test plan with the 200-ft-wide entrance at Pier 45 (Plan 1) revealed excessive wave heights in the proposed small-craft mooring area (wave heights in excess of 4.5 ft) and in the historical vessel mooring area (wave heights in excess of 3.0 ft). Visual observation indicated substantial wave energy entering the harbor through the 200-ft-wide entrance at Pier 45.

64. Modifications to the western end of the original solid breakwater structure (Plans 2-5) indicated that a 300-ft-long extension (Plan 4) would be

necessary to reduce wave heights in the proposed small-craft mooring area to the 1.0-ft criterion. The initial test plan (Plan 1) resulted in wave heights of only 1.1 ft in this area. Addition and/or removal of the structure at its western end only slightly changed wave heights in the harbor for the 10-sec, 2-ft swell conditions from west-northwest.

65. Modifications at the eastern end of the original solid breakwater (Plans 6-9) revealed that even with a 400-ft-long extension (Plan 9) the wave-height criterion in the proposed small-craft mooring area was exceeded. With the 400-ft-long east extension of the outer breakwater, additional modifications at the entrance involving structure changes at Pier 45 (Plans 10-15) indicated that a cumulative baffled breakwater length of 585 ft (Plan 14) appeared to be optimum with regard to meeting the established wave-height criteria in the harbor and cost of construction. With the 300-ft-long east extension of the outer breakwater (Plans 16-20), the combined solid and baffled breakwaters of Plan 19 (total cumulative length of 555 ft) attached to Pier 45 were considered optimum with regard to wave protection provided and construction costs.

66. The breakwater configuration with the 165-ft-wide entrance at Pier 45 (Plan 21) yielded 1.8-ft wave heights in the proposed small-craft mooring area and 2.1-ft wave heights in the historical vessel mooring area for 10-sec, 2-ft swell conditions from west-northwest. The 200-ft-long west extension of Plan 23 reduced wave heights in the small-craft mooring area to 1.0 ft and wave heights in the historical vessel mooring area to 1.5 ft (both within the established criteria). The western end of the structure terminated 100 ft bayward of the previously tested Plan 1 (200-ft-wide opening at Pier 45) configuration which would provide increased tidal flow within the harbor and required less structure length.

67. For 10-sec, 3-ft swell conditions from west-northwest, the western end of the Plan 21 breakwater had to be increased by 300 ft and a 700-ft-long solid breakwater had to be attached to Municipal Pier (Plan 32) to reduce wave heights in the harbor to the established wave-height criteria. Since this plan would probably have an adverse effect on tidal circulation, water quality, etc., in the harbor, and due to the uncertainty of the frequency of occurrence of 10-sec, 3-ft swell conditions from the Golden Gate (probably greater than 50-year recurrence interval) and the cost of construction, this wave condition was not used as a basis for harbor design. The 200-ft-long

west extension of Plan 23 was considered the optimum plan (based on 10-sec, 2-ft design waves). It should be noted, however, that if such a swell condition (10-sec, 3-ft waves) does occur during the life expectancy of the Plan 23 harbor configuration, wave heights in the proposed small-craft mooring area and the historical vessel mooring area may be as high as 1.8 and 2.0 ft, respectively.

68. An evaluation of wave-height data for various baffled breakwater configurations (Plans 34-39) and the outer breakwater configuration with the 165-ft-wide entrance at Pier 45 revealed that the cumulative 585-ft baffled breakwater length of Plan 38 appeared to be optimum in regard to wave conditions in the harbor for test waves from northeast.

69. The Plan 38 breakwater configurations (1,585-ft-long solid outer breakwater, 585-ft-long cumulative baffled breakwaters) resulted in wave heights within the established criteria in the harbor for test waves from all directions with both the 0.0- and +5.7 ft swl's, with the exception of 10-sec, 2.5- and 3.0-ft test waves from west-northwest. These swell conditions (10-sec, 2.5- and 3.0-ft waves) were not considered the basis for harbor design due to the uncertainty of their recurrence intervals; therefore at this point Plan 38 appeared to be the optimum plan.

70. Due to the protection provided the Aquatic Park area by the offshore breakwater of Plan 38, sediment movement in a westerly direction was inhibited for test waves from the northeast counterclockwise through the north-northwest. Test waves from the northwest and west-northwest continued to move material toward the east (similar to existing conditions). These tests indicated that material may move predominantly in an easterly direction (provided the severe wave climate is available). Only the most severe locally generated storm waves and swell conditions resulted in substantial movement of material. Observations revealed no reflected energy from the structure that may tend to erode the beach in Aquatic Park.

71. Further examination of the Plan 38 breakwater configuration indicated excessive wave heights (8.8 to 9.2 ft) in the entrance for test waves from the northeast due to reflected wave energy off the baffled structures installed at Pier 45. Considering wave heights obtained for the various baffled breakwater configurations of Plans 41-51 for test waves from northeast and north-northeast, several plans (Plans 45 and 49-51) met the established wave-height criteria in the harbor. Considering test waves from both

directions and the two swl's, maximum wave heights in the entrance were 5.1 ft for Plans 45, 49 and 50, and 4.3 ft for Plan 51. Plan 51 (420-ft cumulative length of baffled breakwaters) was considered the best baffled breakwater configuration tested to this point; however, the impracticality of construction of this type of structure in the prototype precluded further testing.

72. Test results for the various segmented breakwaters (Plans 52-63) with the 1,585-ft-long solid outer structure and 165-ft-wide entrance indicated that several of these test plans (Plans 54, 58, and 60-63) met the desired wave-height criteria in the harbor. Maximum wave heights in the entrance for Plans 54, 58, and 60-63 were 5.4, 4.9, 5.5, 5.6, 4.9, and 4.6 ft, respectively, considering both the northeast and north-northeast directions and the 0.0- and +5.7 ft swl's. Plan 63 (500-ft-long segmented breakwater with 28-ft solid sections and 6-ft openings and a 200-ft-long solid breakwater attached to Pier 45) appeared to be the best segmented plan to this point with regard to wave heights in the entrance and the various mooring areas of the harbor.

73. Tests conducted for the incremental removal of various sections of the 1,585-ft-long outer solid breakwater at its eastern end in conjunction with various segmented breakwater configurations (Plans 64-75) initially appeared promising for test waves from the north-northeast. Many of these plans resulted in wave heights less than 4.0 ft in the entrance and within the established criteria in the harbor area. Wave heights for test waves from northeast, however, revealed that none of the test plans met the specific criterion in the proposed small-boat mooring area. Also, wave heights in the entrance ranged from 4.4 to 6.8 ft for the various test plans from this direction.

74. Wave-height tests for the solid outer breakwater with the reoriented eastern end and the 165-ft-wide entrance in conjunction with various segmented breakwater configurations at Pier 45 (Plans 76-90) revealed that several of these plans (Plans 76-78, 80, 82-84, and 88) met the established wave-height criterion in the harbor. Maximum wave heights in the entrance were 4.8, 4.4, 3.9, 4.3, 4.4, 4.7, 4.3, and 5.9 ft for Plans 76-78, 80, 82-84, and 88, respectively. Plan 78 (cumulative segmented breakwater lengths of 400 ft, 28-ft solid sections and 6-ft openings) appeared to be the optimum plan tested to date considering wave protection afforded the entrance and the harbor, ease of navigation, and cost of construction. The 150-ft-long diagonal

segmented breakwater between the fingers of Pier 45 appeared to reflect wave energy away from the entrance. The reoriented 1,560-ft-long solid outer breakwater also would appear to provide better navigation conditions than many of the previously tested plans.

75. Wave heights for Plan 78 for test waves from north-northeast and north met the established criteria in the harbor. Maximum wave heights at the entrance were 4.5 ft for 4.8-ft incident waves from north-northeast. Considering the 90 plans tested in the model, Plan 78 was determined the optimum improvement plan based on wave heights in the entrance and within the harbor, ease of navigation through the entrance, and the total length of breakwater structure required.

76. Locally generated short-period storm waves (approximately 4-sec wave period) could occur concurrent with longer period Pacific Ocean swell propagating through the Golden Gate. Although the simultaneous occurrence of two wave trains could not be simulated in the physical model, the significant wave height resulting from the simultaneous occurrence of the two wave trains may be estimated using

$$H_{1/3} = \sqrt{H_{sea}^2 + H_{sw}^2}$$

where the subscripts sea and sw represent the significant wave height from the separate sea and swell tests. For incident sea and swell waves from the west-northwest direction, wave-height criteria would be exceeded only for the +5.7 ft water elevation at gage 4 by 0.1 ft. The criterion also would be exceeded by 0.1 ft at gage 8 for sea from the northwest and swell from the west-northwest. The remaining locally generated incident sea directions are unlikely to result in the simultaneous occurrence of sea and swell due to the local wind direction.

PART III: HARBOR OSCILLATION EVALUATION

Numerical Model

77. The numerical model, in the present study, uses a hybrid finite element solution to the generalized Helmholtz equation in shallow water originally developed by Chen and Mei (1974). The model has been successfully applied to several study areas by WES and has been expanded to incorporate variable depth bathymetry and the dispersion relationship from linear wave theory (Houston 1976). The effects of bottom friction and boundary absorption on harbor resonant response have been incorporated recently into the model by Chen (1984). This more accurately models the conditions seen in prototype data and physical model testing, and is consistent with theoretical arguments of energy dissipation.

78. Applying linear wave theory to the governing continuity and momentum equations and noting that all the dependent variables are periodic in time with angular frequency ω yields the following governing equation (Chen 1984):

$$\nabla \bullet \lambda c c_g \nabla \phi + \frac{c_g}{c} \omega^2 \phi = 0 \tag{1}$$

where

$c = \omega/k$, the phase velocity

$c_g = (1/2)c\ (1 + 2kh/\sinh(2kh))$, the group velocity

ϕ = the complex velocity potential

$k = 2\pi/L$, wave number

The bottom friction factor λ is assumed proportional to the maximum flow speed at the bottom in the flow field and defined as

$$\lambda = \frac{1}{1 + \dfrac{\beta a_o}{h \sinh (kh)}\ ie^{i\gamma}} \tag{2}$$

where

β = dimensionless parameter that varies spatially

a_o = incident wave amplitude

h = local water depth

γ = phase shift between the wave field and the bottom friction

For example, when $\beta = 0$ then $\lambda = 1$ and Equation 1 reduces to Chen and Mei's original equation without bottom friction.

79. The absorptive boundary condition on the solid boundaries adopts the impedance condition used in acoustics in terms of the boundary reflection coefficient k_r to be

$$\frac{\partial \phi}{\partial n} - \alpha \phi = 0 \tag{3}$$

along the boundary with

$$\alpha = ik \frac{1 - k_r}{1 + k_r}$$

and n is the unit normal vector outward from the water domain. Similar to the friction coefficient, when $\alpha = 0$, Equation 3 reduces to a statement of zero velocity normal to the boundary, which is implicit in Chen and Mei's original formulation.

80. A conventional finite element approximation with triangular elements of nodal type is used in the near region, while an analytical solution with unknown coefficients is used to describe the far region as an element of coefficient type. A variational principle using a proper functional is established so that the near and far regions are matched along an outer semicircle bounded in a semi-infinite (or infinite) domain. The coefficients on the semicircle are obtained from the analytical solution for the incident wave direction selected. The analytical solution assumes a constant depth or very mild slope in the far region, and neglects bottom friction in the far region.

81. Within the bounding semicircle the region of interest is discretized into a finite number of coordinate pairs called node points. These node points are related to adjacent node points via triangular elements (three nodes per element). The local depth h and bottom friction factor β are defined at the element level. The absorption coefficients α are specified at boundary elements which are defined as a subset of the nodal and element data. Once the physical geometry of the finite element is defined a series of values of wave period T , wave direction θ , and wave amplitude a_0 can be supplied as input to the model.

82. The finite element solution is obtained from a global matrix of nodal coefficients that is assembled at the element level with respect to the governing equations and specified boundary conditions. The element matrices are symmetric with global bandwidths equal to the maximum numerical difference between adjacent node indices. It follows that the assembled matrix is symmetric with a bandwidth (maximum extent of a nonzero coefficient from the diagonal) equal to the largest element bandwidth. The size of an element is dependent on the depth and the wave period that define the local wavelength. Sufficient accuracy is obtained when the number of node points per wavelength is on the order of eight or larger (Houston 1976). Elements with equilateral sides are most convenient since this minimizes the nodal density in addition to maximizing computational accuracy.

83. The assembled matrix is solved using Gaussian elimination with a solution time proportional to the product of the number of unknowns (nodes) and the bandwidth squared. The model solution for the complex velocity potential ϕ at each node point is represented as an amplification factor and corresponding phase angle. In general, the solution consists of a standing wave component and a progressive wave component.

Finite Element Grids for Existing Conditions and Recommended Plan

84. Plate 35 represents the finite element mesh used for the present pier and harbor configuration and consists of 741 nodes, 1,343 triangular elements, and 99 boundary elements. The range of wave periods studied was 30 to 600 sec and thus the shallow-water approximation (using $h \leq 45$ ft)

$$\frac{h}{L} = \frac{h}{T(gh)^{1/2}} = \frac{h^{1/2}}{5.67T} = \frac{(45)^{1/2}}{5.67(30)} = \frac{1}{25} \tag{4}$$

was used. The bathymetry within the discretized area varied from 3 ft (Municipal Beach) to 53 ft (offshore of Pier 45) and was assembled from several data sources. The distance between nodal points was selected based on the minimum period and local bathymetry and ranged from 70 to 150 ft. Only one mesh was used in the study area for the entire period range; the relatively low cost of solution, ease of data manipulation, and project deadline were considered in relation to the additional time required to develop a coarser grid, even though the resulting computational costs would be greatly reduced. Orientation of the grid semicircle was determined with respect to the shoreline on either side of the study area.

85. The size of the grid was based primarily on the proposed breakwater and harbor complex with the addition of the Municipal Pier enclosure, resulting in a semicircle diameter of 3,200 ft. Although Municipal Pier itself would be insignificant (as an obstacle) in attenuating long-period wave energy, this area was included for several reasons: (a) possible adverse effects with the addition of the breakwater, (b) possible modifications made to the pier itself as part of the proposed breakwater plan, (c) direction of the significant long-period wave energy, (d) resonant interaction with the breakwater and inner wharf areas, and (e) placement of semicircle to best satisfy the model's boundary assumption (purely reflective condition extending to infinity on either side of the semicircle). The principal wave direction (azimuth) chosen was 272 deg to reflect the direction of approach for long-period energy entering San Francisco Bay (via the Golden Gate) from the Pacific Ocean during extreme storm events. Other directions of approach were not used due to the limited fetch around the bay. Comparison of wave data collected the past 2 years from the wharf area with wave data collected off the California coast (USACE and State of Calif. 1982, 1983, and 1984) indicates a trend where all occurrences of significant wave energy in the inner harbor (15 to 100 sq cm) are coincident with significant offshore energy (5,000 to 24,000 sq cm).

86. In terms of low-frequency attenuation, the pier structures within the study area were not included in the analysis due to the relatively sparse spacing of the supporting piles. Since the study area was relatively small with respect to the wave period (wavelength) range, the bottom friction factor was set to $\beta = 0.1$ for all elements. The value of α for the boundary elements ranged from $\alpha = 0.20 (K_r = 0.96)$ on the proposed breakwater to $\alpha = 0.80 (K_r = 0.85)$ along the Municipal Beach area. Future experimental and theoretical work needs to be conducted before quantitative estimates for α and β can be chosen in these types of analyses. An incident wave height of 1 ft ($a_o = 1/2$ ft) was used for λ and the subsequent velocity calculations.

87. Plate 36 shows the modified finite element grid for the recommended Plan 78. The total number of node points remains at 741 with some coordinate changes, 39 triangular elements were deleted (but element connectivities

remained the same), and 51 boundary elements were added. The segmented portions of the Plan 78 breakwater were grouped into singular boundary elements approximately 70 ft long with a 15- to 20-ft spacing between elements. Maintaining the same number of node points, adding boundary elements, and subtracting triangular elements minimized the time required to analyze the recommended plan. Except for the modifications made to the grid geometry for Plan 78, all other parameters and procedures were identical with those used for existing conditions discussed in paragraphs 84-86.

Numerical Results

88. The numerical harbor oscillation tests were conducted for existing conditions and revised conditions. Revised conditions used were the optimum plan (Plan 78) based on the short-period wave tests discussed in PART II.

89. Harbor response data initially were calculated for existing conditions and Plan 78 for 1.5-sec increments for 30- to 120-sec wave periods, 3.0-sec increments for 120- to 270-sec wave periods, 15.0-sec increments for 270- to 360-sec wave periods, and 30-sec increments for 360- to 600-sec wave periods for the 272-deg incident wave direction. Data for additional wave periods then were calculated, when necessary, to define resonant peaks.

90. Stations for which wave-height amplification factors (Plates 37-54) were obtained (for existing conditions and Plan 78) are the same as the physical gage numbering and positioning shown in Plate 30. The wave-height amplification factor is defined at any point inside the harbor as the wave height at any point divided by twice the incident wave height. This traditional definition results from the fact that the standing wave height for a straight vertical barrier would be twice the incident wave due to the superposition of the incident and reflective waves.

91. Contour plots of the wave-height amplification factor (Plates 55-65) and vector plots of the normalized maximum current velocity (Plates 66-76) were selected from the peak frequency responses of the harbor. The normalized maximum current velocity at any point in the harbor is defined as the maximum current velocity over one period of the standing wave (oscillation) divided by the amplitude of the incident wave. Since the numerical harbor oscillation model is based on the linearized long-wave equation, the computed velocities are constant in the vertical (depthwise) direction. In addition, the

mathematical form of the current velocity of a harmonic, long-period wave is directly proportional to the amplitude of the long-period wave. Hence, the current velocity associated with the harbor oscillation can be normalized, for convenience, by the incident wave amplitude. Therefore the normalized maximum current velocity at any point in the harbor multiplied by the incident wave amplitude gives the maximum current velocity. An excellent technique for displaying the harbor resonant response can be obtained by plotting contours of wave-height amplification factors over the entire grid. This graphic technique depicts very well the spatial variation of wave-height amplification throughout the harbor.

Test Results

92. Frequency response curves of wave-height amplification versus wave period (range 30 to 600 sec) are shown in Plates 37-54 for selected stations. Existing conditions are plotted together with Plan 78 for relative comparison and discussion of the harbor response. Stations not shown were considered to be similar to neighboring stations shown. Based on these curves, resonant peaks were identified at various stations for existing conditions at 34.5-, 54-, 79.5-, 115.5-, 135-, and 228-sec wave periods and for Plan 78 at 63-, 81-, 115.5-, 147-, and 228-sec wave periods. Contour plots of wave-height amplification (over the entire grid) for these resonant peaks are shown in Plates 55-60 and 61-65 for existing conditions and Plan 78, respectively.

93. At any point in the harbor, horizontal velocities can be calculated from the pressure gradients associated with the spatial changes of the water-surface elevations (wave-height amplification factors). For each of the resonant peaks listed in paragraph 92, vector plots of the normalized maximum current velocities throughout the harbor are plotted in Plates 66-71 and 72-76 for existing conditions and Plan 78, respectively. The velocities are represented by lines whose centers lie at the element centroids. Water particles move horizontally back and forth in the line direction. Since the velocities have been normalized by the amplitude of the incident wave, $a_o = 0.5$ ft, the velocities are in units of feet per second per foot of incident wave amplitude.

Comparison of Prototype Data and Numerical Model Results

94. Long-period wave data were collected at three locations within the

Fisherman's Wharf study area during December 1982-April 1984. Comparison of the surge data collected typically shows very little energy within the 32- to 102-sec bands at any of these gages. At the innermost harbor gage at Alioto's Pier, the 171- to 256- and 256- to 512-sec bands typically contain 75 to 85 percent of the total surge energy during storm events. This trend also occurs at the other two surge gages but the total energy is smaller than the surge energy at Alioto's Pier. These trends can be qualified with the numerical results by comparing sta 15 (Plates 51-52) with the Alioto's Pier gage. As shown in Plate 52, there is a fairly broad resonant response region centered at 228 sec with a maximum amplification factor of 9. This resonant response is in fact predominant within the entire analysis and affects the entire harbor region as shown in the the amplification contour plot of Plate 60. This is often referred to as the primary or "pumping" mode of a harbor. This primary mode agrees roughly with the peak period bands of wave energy seen in the prototype data, although the peak amplification response was not as great as the numerical results (when comparison between surge gages and corresponding stations in the numerical analysis is made). One likely source for the discrepancy between the prototype and numerical results would be the time-dependency of the actual incident wave energy (spectral versus monochromatic waves). Even though the numerical results below 180 sec from sta 15 indicate that several periods of peak amplification could exist, comparison with the prototype data is not possible since very little energy is present in the 32- to 171-sec period bands.

Plan Evaluation

95. The resonant response in the inner harbor area at sta 11, 12, and 15 for existing conditions and Plan 78 indicates that the 34.5-sec response has been reduced 20 to 50 percent; the 54-sec resonance has been shifted to approximately 63 sec and has increased up to 25 percent for sta 12, although the width of this resonance has been reduced by 30 percent. The 79.5-sec resonance has virtually remained unchanged and has shifted slightly to 81.0 sec. A weaker 94.5-sec resonance (compared with paragraph 92 resonant frequencies) has been reduced up to 50 percent with a similar reduction noted for the 115.5-sec resonance.

96. The 134-sec resonance for existing conditions has shifted to

147 sec with an increase of approximately 20 percent in the peak amplitude for Plan 78. The 147-sec peak of Plan 78 is sharper than the 134-sec peak for existing conditions; also, the energy around 134 sec for Plan 78 has been reduced 50 to 60 percent. Outside the inner harbor area the 147-sec peak resonance has, in some areas (sta 3), increased up to 100 percent; but the amplification factor is about 2.5, significantly less than the peak amplification factors of the inner harbor area. Station locations are shown in Plate 30.

97. The 228-sec "pumping" mode resonant peak position is the same for Plan 78 as the existing conditions with a 15 to 20 percent reduction throughout the inner harbor area. Although the peak has been reduced for Plan 78, the response curve above 228 sec is broader with a 10 to 20 percent increase in the amplification from 260 to 420 sec versus existing conditions. The modes of oscillation for the resonant conditions discussed in paragraphs 95-97 for both existing conditions and Plan 78 are shown in Plates 55-65. Areas of maximum amplification indicate vertical rise and fall of the water surface. Maximum currents develop in the nodal areas (areas of minimum wave-height amplification between amplification peaks) and the current patterns for corresponding wave-height amplification plots are shown in Plates 66-76. The nodal areas are generally areas where adverse ship mooring conditions may develop.

98. As discussed in paragraph 94, little long-period wave energy was observed in the Fisherman's Wharf area during the prototype data acquisition period for periods less than 171 sec. Had long-period wave energy been present, the harbor oscillation results indicate that modes of oscillation less that 171 sec would have developed. The long-period wave energy, not observed for existing conditions, should not occur for Plan 78 as well; and the only resonant oscillation expected to develop for Plan 78 is the 228-sec mode.

99. Based on the results of the harbor oscillation evaluation, Plan 78 will result in decreased maximum long-period wave-height amplification in the inner harbor area due to the lack of observed long-period wave energy at periods less than 171 sec (wave energy is not present to excite resonant oscillations less than 171 sec) and the decrease in amplification for Plan 78 for the 228-sec mode.

PART IV: FISHERMAN'S WHARF SHIP MOORING ANALYSIS

Method of Analysis

100. The scope of the ship mooring analysis for the historic fleet is to determine conditions under which significant long-period ship motions could occur, and the effect of the proposed breakwater on the motions of the ships. Short-period ship motion is attenuated by the improvement plans considered in PART II. Within the Fisherman's Wharf area, the historic fleet is moored on either side of Hyde Street Pier (Figure 7). At present, the historic fleet consists of five vessels: the ***C. A. Thayer, Eureka, Hercules, Eppleton Hall,*** and ***Alma*** which are either listed or nominated for inclusion on the "National Register of Historic Places." The historic fleet is part of the San Francisco Maritime State Historic Park maintained by the Golden Gate National Recreation Area (under administration of the National Park Service). In the past there have been several occasions during which significant ship motions caused anchor lines to move, mooring lines to part, and ship and pier areas to be damaged.

101. The ship mooring analysis, for this study, was based principally on a report by Raichlen (1968). This model has the advantages of a low-cost solution to the ship motion problem, can be used with limited ship characteristic data, and has the ability to incorporate geometric asymmetries and nonlinear elastic properties of the ship mooring systems. Model assumptions (discussed briefly in the following paragraph) and lack of measured ship motion data for the historic fleet limit interpretation of the results to a relative comparison of ship motion.

102. In the model, the ship is idealized as a block body positioned in a standing wave field, linear wave theory is used, and the bow-to-stern axis of the ship is perpendicular to the nodal lines. Thus the motion considered in the analysis is the surging motion (horizontal motion) in the bow-to-stern direction. The standing wave acts as the dynamic force moving the ship from equilibrium while the mooring lines counteract this motion and act as a restoring force that holds the ship in dynamic equilibrium.

103. The model allows for nonlinear asymmetric mooring lines by inclusion of the geometry of the mooring lines and assuming a stress-strain relation

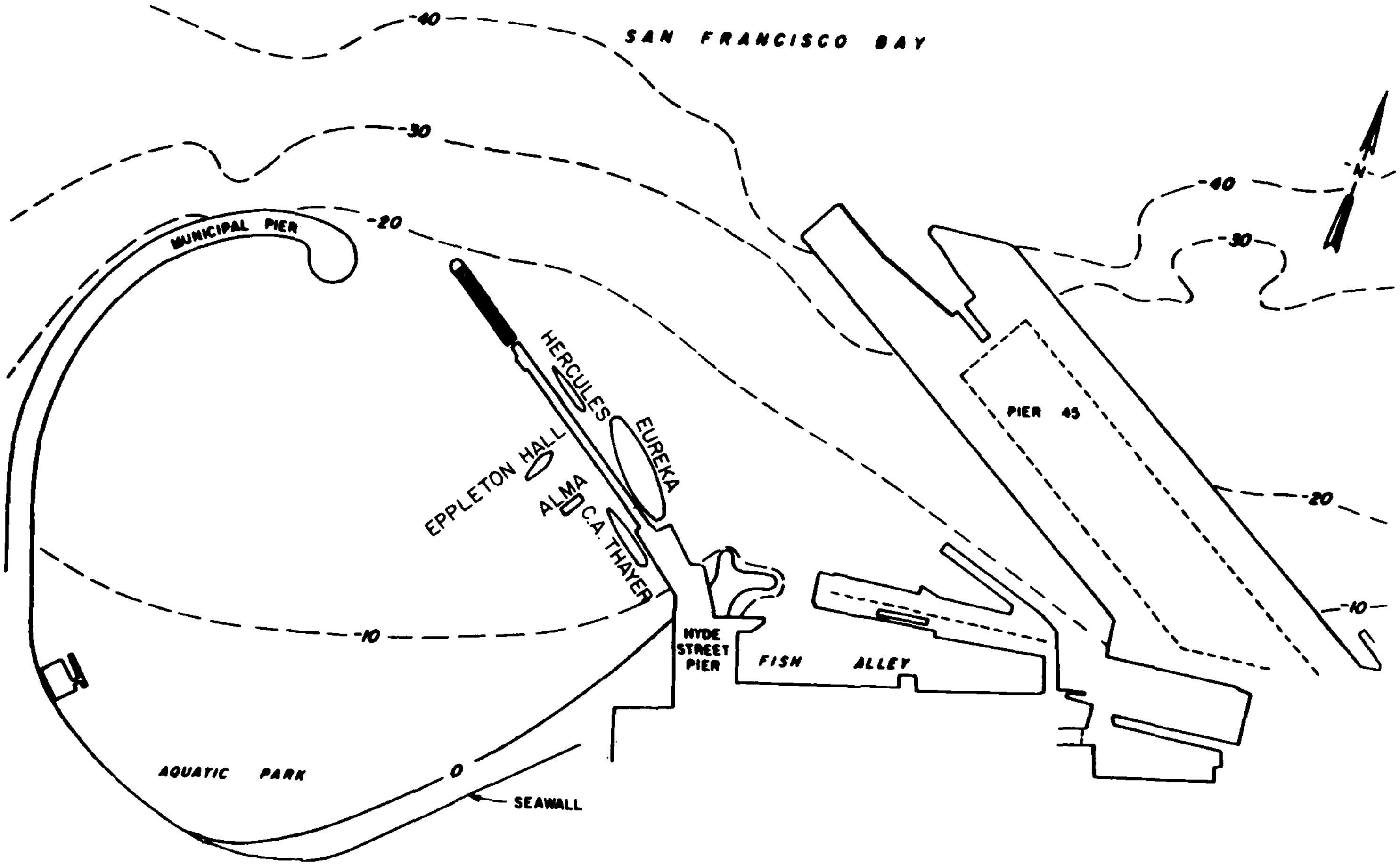

Figure 7. Historic fleet mooring locations around Hyde Street Pier

$$\frac{T^*}{T^*_{Brk}} = R\varepsilon^m \tag{5}$$

where

T^* = line tensile force

T^*_{Brk} = approximate average breaking strength

ε = unit elongation

R,m = coefficients dependent on line type

Raichlen (1968) includes information on lines composed of manila, dacron, polypropylene, and nylon. Additional information on steel-wire mooring ropes was obtained from Wilson (1967) and analysis of chain-anchor lines follows the catenary analysis described by Berteaux (1976). The analysis of chain-anchor lines is transformed into an equation of the same form as Equation 5 using a least-squares curve fitting of the theoretical calculations.

104. The solution to the ship motion problem is obtained assuming a harmonic response (equal to the standing wave period) of the mooring lines and thus neglects harmonics other than the fundamental. The governing equation obtained by Raichlen (1968) is

$$\left(\frac{2\pi}{T}\right)^2 + \frac{2\pi}{T}\frac{\zeta}{x} - \frac{1}{\pi x C_m M}\int_0^{2\pi} F_r \cos\theta d\theta = 0 \tag{6}$$

where

T = standing wave period

ζ = wave function

x = amplitude (displacement) of ship motion about mean position

C_m = virtual (added) mass coefficient in surge

M = ship mass

The restoring force F_r is obtained from summation of the normal forces T^*_n resisting motion in the bow and stern directions, respectively. The analysis is simplified by a least-squares fitting of polynomial curves to the bow and stern summations, which yields a closed form solution of Equation 6. The wave function ζ is a function of the ship's shape (length and draft), the water depth, wave period, and wave amplitude. Using the shallow-water approximation ($h/L \leq 0.04$) and that the ship length is much shorter than the wavelength yields a simplified form of Raichlen's (1968) definition as

$$\zeta = a(gh)^{1/2}\left(\frac{2}{D} - \frac{1}{h}\right)\sin\frac{2\pi b}{L} \tag{7}$$

where

- a = standing wave amplitude
- g = gravity force
- h = water depth
- D = ship draft
- b = distance from reflecting surface to center of ship
- L = wavelength

For a given maximum ship displacement, the range of possible wave periods occur where

$$\zeta = \pm a(gh)^{1/2} \quad \frac{2}{D} - \frac{1}{h} \tag{8}$$

The maximum displacement occurs when $\left|\sin 2b/L\right| = 1$, which is coincident with the nodal points of a standing wave.

Historic Fleet Mooring Characteristics

105. The approximate physical dimensions and present estimated gross weights of the five historic ships are given in the following tabulation. The weight of each ship was obtained by defining the hull shape from drydock photographs, limited ship drawings, naval architecture hull shapes, and the present ship draft.

Ship	Length ft	Beam ft	Draft ft	Displacement tons	Water Depth ft
Alma	60.0	22.5	1.5	67.5	20
Eppleton Hall	80.0	24.0	6.0	200.0	20
Hercules	135.0	26.0	15.5	300.0	20
C. A. Thayer	156.0	36.5	9.0	450.0	20
Eureka	280.0	50.0	9.0	2,400.0	20

106. The following tabulation contains the mooring line information for each ship including mooring line geometry, material type, and material size. The historic fleet is moored with lines to Hyde Street Pier, mooring dolphins, and anchors. For ships with mooring lines attached to the pier or dolphins, mooring lines attached to the ship on the side away from the pier/dolphin are run to anchors out in the bay. The definition of the mooring line geometry follows the right-hand rule with: +x-axis in the port-to-starboard direction,

direction, and +y-axis in the stern-to-bow direction, and +z-axis vertically upward. The origin of each line is taken from its position on the ship and extends outward to its mooring position. Thus, for example, lines resisting motion in the stern direction would have positive y-coordinates, with similar interpretations of the other coordinate directions. In the case of a composite line (line whose length contains two or more material sizes or material types) the listed information represents the response of the composite line.

Ship	Line	x, ft	y, ft	z, ft	Diameter, in.	Material
Alma	1	0.0	125.0	-20.0	0.875	Chain
	2	0.0	-56.5	0.0	2.500	Polypropylene*
Eppleton Hall	1	-31.5	102.0	0.0	3.000	Nylon
	2	8.5	81.0	0.0	3.000	Nylon
	3	93.5	45.5	0.0	2.500	Polypropylene
	4	14.5	-84.0	-20.0	1.250	Chain*
	5	-60.0	-60.0	-20.0	1.250	Chain*
Hercules	1	-22.0	91.0	0.0	2.500	Dacron
	2	-23.0	153.0	0.0	1.500	Braided wire
	3	136.5	62.0	-20.0	0.875	Chain*
	4	126.0	-81.5	-20.0	0.875	Chain*
	5	-15.5	-63.0	0.0	2.000, 3.000	Nylon (2 pieces)
	6	-12.0	-6.5	0.0	2.000	Polypropylene
	7	22.0	-25.0	0.0	2.000	Polypropylene
	8	-12.5	42.5	0.0	2.000	Polypropylene
	9	-12.0	-58.5	0.0	3.000	Nylon
	10	-12.0	-9.5	0.0	3.250	Woven wire
	11	-22.0	22.0	0.0	3.000	Polypropylene (2 pieces)
C. A. Thayer	1	-223.5	45.5	-20.0	1.375	Chain
	2	19.0	85.0	0.0	1.375	Chain
	3	12.0	105.5	0.0	2.000	Dacron
	4	22.0	42.5	0.0	3.000	Polypropylene
	5	11.0	-82.0	0.0	2.500	Nylon
	6	4.0	31.5	0.0	2.250	Polypropylene
	7	12.5	-11.0	0.0	2.250	Polypropylene (2 pieces)
	8	19.0	-23.0	0.0	2.250	Polypropylene (2 pieces)
	9	34.5	-54.5	0.0	2.750	Dacron (2 pieces)
	10	6.5	-134.0	0.0	1.375	Chain*
	11	-194.0	-83.5	-20.0	1.500	Chain

(Continued)

* Representation of a composite mooring line.

Ship	Line	x, ft	y, ft	z, ft	Diameter, in.	Material
Eureka	1	64.5	-9.5	0.0	3.000	Nylon
	2	60.0	5.5	0.0	3.000	Nylon
	3	116.5	189.0	-20.0	1.500	Chain
	4	-102.5	192.0	-20.0	1.500	Chain
	5	-58.5	4.5	0.0	3.000	Polypropylene (2 pieces)
	6	-56.5	-42.5	0.0	3.000	Polypropylene (2 pieces)
	7	4.0	-19.0	0.0	1.500	Chain
	8	-4.0	-19.0	0.0	1.500	Chain
	9	0.0	-250.0	-10.0	1.250	Chain

Ship Mooring Analysis Results

107. The computed results of the ship mooring analysis are shown in Plate 77. The ζ values were derived from Equation 8 using a standing wave amplitude $a = 0.1$ ft. For the purpose of the analysis it was assumed that there were no slack lines, although the analysis has the capability of handling mooring lines with different amounts of slack. The motions shown in Plate 77 are port-to-starboard for the *Hercules*, *C. A. Thayer*, and *Eureka*, and bow-to-stern for the *Alma* and *Eppleton Hall*. The port-to-starboard calculations were carried out, in a manner similar to the bow-to-stern calculations, modifying the virtual mass coefficient, C_m , to account for the reciprocal beam-to-length ratio.

108. The preceding analysis assumed no slack in the mooring lines and introduction of slack will affect the analysis results. Wilson (1967) has shown that as these types of rope lines are stretched, permanent deformations occur although the elastic characteristics remain roughly the same. Even if all lines are initially taut, slack in these lines should be expected to develop. Whether this entirely explains the occurrence of slack lines (for instance, intentional slack may be introduced to allow the ships to move freely over the tidal range), visual inspection of the historic ships does indeed indicate there are lines with substantial slack of up to several feet. Raichlen (1968) shows that introduction of uniformly slack lines into the analysis shifts the ship displacement curves to higher wave periods. Shown in Plate 78 are the results of introduction of slack lines into the analysis of the historic fleet (1-ft slack on all line), with an approximate 10 to 30 percent increase in the wave periods versus the results shown in Plate 77.

109. The results from the analysis shown in Plates 77 and 78 indicate that the historic ships would be most significantly affected by waves in the period range less than approximately 50 sec. When comparison is made with the field data collected at Fisherman's Wharf (USACOE 1983), significant wave energy typically occurs in the short period (4 to 22 sec) and long period (171 to 512+ sec) bands simultaneously. Only under conditions where the peak energy is in the shortest period bands (4 to 6 sec, 6 to 8 sec) were there times during the prototype data observation period when insignificant long-period energy existed. The comparison of a very qualitative log of weather, sea, ship motions and ship maintenance* with the field data for 1983 shows considerable agreement between the two data sets for the larger storm events. From the comparison of data sets, it is difficult to conclude whether the short- or long-period energy was the major source of the boat motions and each source may significantly contribute to the total ship motion. In the long-period range, the observed wave data indicate that very little wave energy is present in the 32- to 171-sec period range as discussed in paragraph 94. The harbor oscillation numerical results for the long-period resonant model of oscillation indicated that the primary or fundamental mode of oscillation would occur at 228 sec for both existing conditions and Plan 78. As shown in Plates 60 and 65, the modes of oscillation develop in a similar pattern near the Hyde Street Pier where the historic fleet is moored. Current patterns for the two conditions are shown in Plates 71 and 76 and are quite similar as well. Maximum normalized currents shown in Plates 71 and 76 for the locations of the historic ships are:

Ship	Maximum Current, fps		Percent Change
	Existing Condition	Plan 78	
Alma	4.00	4.55	14
Eppleton Hall	3.60	4.25	18
Hercules	3.10	3.20	3
C. A. Thayer	5.20	5.40	4
Eureka	4.30	4.30	0

The velocity magnitude near the *C. A. Thayer, Hercules,* and *Eureka* is relatively unaffected by Plan 78 in the long-period range and the change in predicted ship motions will be insignificant.

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* Personal communication, National Park Service (1984).

110. The normalized maximum current increased 18 and 14 percent for the *Eppleton Hall* and *Alma*, respectively. The *Eppleton Hall* and *Alma* are moored southwest of the Hyde Street Pier near the Aquatic Park. Since the velocity calculations are a direct result of the harbor amplification results, the changes in current velocities are representative of linear changes of an idealized standing wave such as that used in the ship motion analysis. For a fixed wave period outside the range of large-ship displacements (in this case T > 100 sec), small changes in standing wave amplitude will cause nearly linear changes in ship displacement. Thus, for the *Eppleton Hall* and *Alma*, the predicted long-period ship surge motion will increase 18 and 14 percent, respectively. The change in predicted long-period ship surge motion for the *Eppleton Hall* and *Alma* can be decreased to the same level as the surge motion predicted for existing conditions by mooring the two ships along the east or west side of Hyde Street Pier where lower current velocities (Plate 76) were calculated for Plan 78 in comparison with current velocities near the current mooring locations (Figure 7). The increased long-period velocities for the 228-sec oscillation in the vicinity of the mooring location shown in Figure 7 for the *Eppleton Hall* and *Alma* result from the decreased area between the southwest end of the breakwater and the shoreline even through the maximum amplitude of the 228-sec oscillation decreased 15 to 20 percent in the inner harbor area near gages 13 to 15. As discussed in paragraph 109, the results of the ship motion analysis indicate that the ships in the historic fleet will be most significantly affected by short-period wave conditions (periods less than approximately 50 sec).

111. For short-period waves, Plan 78 reduces wave heights to the maximum wave-height criterion of 1.5 ft or less and should provide adequate protection against incident short-period wave attack. Maximum short-period wave heights in the vicinity of the Hyde Street Pier (gages 6 to 9) were from the north and north-northeast for the 0.0- and +5.7 ft swl's and for Plan 78 the maximum wave heights from these two directions were reduced by 73 and 74 percent, respectively.

PART V: CONCLUSIONS

112\. Based on the results of the physical wave model investigation reported herein, it was concluded that:

a. Existing conditions are characterized by very rough and turbulent wave conditions in the various mooring areas of the harbor during periods of storm-wave attack.

b. For existing conditions, sediment in the Aquatic Park area migrated in both the easterly and westerly directions depending on the angle of wave approach. This movement occurred for only the most severe locally generated storm wave conditions from the various test directions and swell conditions approaching from the Golden Gate.

c. The originally proposed improvement plan with the 1,450-ft-long solid outer breakwater with a 200-ft-wide entrance at Pier 45 (Plan 1) resulted in excessive wave heights in the harbor due to locally generated wave energy entering through the entrance.

d. For the originally proposed improvement plan with the 1,450-ft-long solid breakwater and 200-ft-wide entrance at Pier 45 (Plan 1), the 1.0-ft wave-height criterion in the proposed small-craft mooring area was exceeded by 0.1 ft for 10-sec, 2-ft swell conditions from the Golden Gate. A 300-ft-long west breakwater extension (Plan 4) was required to reduce swell wave heights to the specified level.

e. For the improvement plans tested with the 200-ft-wide entrance at Pier 45 and a 400-ft-long east extension of the outer breakwater (Plans 9-15), Plan 14 (cumulative baffled breakwater length of 585 ft) appeared to be optimum considering wave protection afforded the harbor and construction costs.

f. For the improvement plans tested with the 200-ft-wide entrance at Pier 45 and a 300-ft-long east extension of the outer breakwater (Plans 8 and 16-20), the combined solid and baffled breakwaters of Plan 19 (total cumulative length of 555 ft) appeared to be optimum considering wave protection afforded the harbor and construction costs.

g. For the improvement plan and breakwater configuration with the 1,385-ft-long solid breakwater and a 165-ft wide entrance at Pier 45 (Plan 21), a 200-ft-long west breakwater extension (Plan 23) was required to reduce wave heights to within the established criteria in the harbor for 10-sec, 2-ft swell conditions from the Golden Gate.

h. For the breakwater configuration with the 1,385-ft-long solid breakwater and the 165-ft-wide entrance at Pier 45 (Plan 21), a 300-ft-long west breakwater extension and a 700-ft-long structure attached to Municipal Pier (Plan 32) were required to meet the 1.0-ft wave-height criterion in the proposed small-craft mooring area for 10-sec, 3-ft swell conditions from the Golden Gate.

i. For the initial improvement plans tested with the 1,585-ft-long solid breakwater with the 165-ft entrance and the various baffled breakwater configurations at Pier 45 (Plans 34-39), Plan 38 (cumulative baffled breakwater length of 585 ft) appeared to be optimum considering wave protection provided the harbor.

j. The protection provided by the 1,585-ft-long outer solid breakwater (165-ft-wide entrance at Pier 45) of Plan 38 inhibited sediment movement in a westerly direction in the Aquatic Park area. Severe storms from west-northwest and northwest may result in net movement of sediment to the east. Reflections off the outer breakwater will not result in any adverse impacts on sediment in the Aquatic Park area.

k. For the Plan 38 baffled breakwater configuration (cumulative length of 585 ft), excessive wave heights (in excess of 9 ft) occurred in the entrance due to reflected wave energy from the baffled structure.

l. For the additional improvement plans tested with the 1,585-ft-long solid outer breakwater with the 165-ft entrance and various baffled breakwater configurations at Pier 45 (Plans 41-51), Plan 51 (cumulative baffled breakwater length of 420 ft) appeared to be optimum considering wave heights in the entrance and wave protection provided the harbor.

m. For the improvement plans tested with the 1,585-ft-long solid outer breakwater with a 165-ft-wide entrance and various segmented breakwater configurations at Pier 45 (Plans 52-63), the combined solid and segmented breakwaters of Plan 63 (total cumulative length of 700 ft) appeared to be optimum considering wave protection afforded both the entrance and the harbor.

n. All the improvement plans which included the removal of portions of the 1,585-ft-long outer solid breakwater at its eastern end with various segmented breakwater configurations at Pier 45 (Plans 64-75) resulted in excessive wave heights in the entrance and/or within the harbor.

o. For the improvement plans tested with the solid outer breakwater reoriented lakeward with a 165-ft-wide entrance and various segmented breakwater configurations at Pier 45 (Plans 76-90), Plan 78 (cumulative segmented breakwater length of 400 ft) appeared to be optimum considering wave heights in the entrance, wave protection afforded the harbor, and construction costs.

p. Of all the improvement plans tested (Plans 1-90), the 1,560-ft-long outer solid breakwater configuration with the cumulative 400-ft segmented breakwater configuration at Pier 45 (Plan 78) was determined to be the optimum plan tested considering wave protection afforded the harbor and entrance, ease of navigation, and economics.

113. Based on the results of the numerical harbor oscillation study for existing conditions and Plan 78, it was concluded that:

a. Maximum resonant amplification developed at periods of 34.5, 54, 79.5, 115.5, 135, and 228 sec for existing conditions.

b. Maximum resonant amplification developed at periods of 63, 81, 115.5, 147, and 228 sec for Plan 78.

c. Observed long-period wave data for existing conditions indicated that long-period wave energy was generally present at periods greater than 171 sec but that possible modes of oscillation less than 171 sec did not develop.

d. The resonant peak of the fundamental mode of oscillation for Plan 78 at 228 sec developed with peak amplification decreasing 15 to 20 percent throughout the inner harbor area.

114. Results from the ship motion analysis in terms of a qualitative analysis indicate that the fundamental periods for large ship motions are predominantly below 50 sec for the historic fleet. Thus, for the case of short-period energy, a significant reduction in wave heights is to be expected in the Hyde Street Pier area which in turn will reduce the ship motions of the historic fleet. Maximum short-period heights are reduced by 73 to 74 percent for Plan 78.

115. Based on the results of the long-period ship motion analysis, it was concluded that:

a. The fundamental model of oscillation develops in a similar manner for existing conditions and Plan 78 near the Hyde Street Pier and the historic fleet.

b. The surge motion of the ***Eureka, Hercules,*** and ***C. A. Thayer*** will be similar for existing conditions and Plan 78 in the long-period range.

c. The calculated long-period surge response increased 14 and 18 percent for the ***Alma*** and ***Eppleton Hall,*** respectively, due to the increased velocities of the resonant oscillation at 228 sec.

d. The mooring location of the ***Alma*** and ***Eppleton Hall*** can be selected to decrease predicted long-period surge motion to the same level as for existing conditions.

The combined ship motion from both short- and long-period wave conditions will be reduced due to the significant attenuation of incident short-period waves along the Hyde Street Pier. The corresponding increases in resonant oscillation velocities for mooring locations west of the Hyde Street Pier (14 to 18 percent increase) and along the Hyde Street Pier (0 to 4 percent increase) are relatively small and, based on the calculated ship motion results, are less significant in influencing ship motion.

116. The combined results of the physical model study, harbor oscillation study, and ship response analysis for the historic fleet moored along the Hyde Street Pier provide a detailed analysis of short- and long-period wave

activity and the resulting predicted ship response changes. In summary, Plan 78 was determined to be the optimum plan tested for short-period wave protection and did not result in significantly changed harbor oscillation or ship mooring conditions.

REFERENCES

Assistant Secretary of the Army (Civil Works). 1983 (Oct). "San Francisco Harbor, California, Fisherman's Wharf Area," Report from the Chief of Engineers, Department of the Army, Washington, DC.

Berteaux, H. O. 1976. Buoy Engineering, Wiley, New York, pp 103-107, 258-259.

Bottin, R. R., Jr., and Chatham, C. E., Jr. 1975 (Nov). "Design for Wave Protection, Flood Control, and Prevention of Shoaling, Cattaraugas Creek Harbor, New York; Hydraulic Model Investigation," Technical Report H-75-18, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Brasfeild, C. W., and Ball, J. W. 1967 (Dec). "Expansion of Santa Barbara Harbor, California; Hydraulic Model Investigation," Technical Report 2-805, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Chen, H. S. 1984. "Effects of Bottom Friction and Boundary Absorption on Water Wave Scattering," submitted to Applied Ocean Research.

Chen, H. S., and Mei, C. C. 1974 (Aug). "Oscillations and Wave Forces in an Offshore Harbor," Report No. 190, Massachusetts Institute of Technology, Ralph M. Parsons Laboratory, Cambridge, Mass.

Dai, Y. B., and Jackson, R. A. 1966 (Jun). "Design for Rubble-Mound Breakwaters, Dana Point Harbor, California; Hydraulic Model Investigation," Technical Report 2-725, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Giles, M. L., and Chatham, C. E., Jr. 1974 (Jun). "Remedial Plans for Prevention of Harbor Shoaling, Port Orford, Oregon; Hydraulic Model Investigation," Technical Report H-74-4, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Houston, J. R. 1976 (Sep). "Long Beach Harbor Numerical Analysis of Harbor Oscillations; Existing Conditions and Proposed Improvements," Miscellaneous Paper H-76-20, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Keulegan, G. H. 1950 (May). "The Gradual Damping of a Progressive Oscillatory Wave with Distance in a Prismatic Rectangular Channel" (unpublished data), National Bureau of Standards, Washington, DC; prepared at the request of the Director, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., by letter of 2 May 1950.

LéMehauté, B. 1965 (Jun). "Wave Absorbers in Harbors," Contract Report 2-122, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.; prepared by National Engineering Science Company, Pasadena, Calif., under Contract No. DA-22-079-CIVENG-64-81.

Noda, E. K. 1972. "Equilibrium Beach Profile Scale-Model Relationship," Journal, Waterways, Harbors, and Coastal Engineering Division, American Society of Civil Engineers, Vol 98, No. WW4, pp 511-528.

Raichlen, R. 1968 (Aug). "Motions of Small Boats Moored in Standing Waves," Contract Report H-68-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Stevens, J. C., et al. 1942 (Jul). "Hydraulic Models," Manuals of Engineering Practice, No. 25, American Society of Civil Engineers, New York.

US Army Coastal Engineering Research Center. 1977. "Shore Protection Manual," Washington, DC.

US Army Corps of Engineers. 1983 (Sep). "Second Interim Report for the Fisherman's Wharf Harbor Study; Data Summary (Appendices)," Special Projects Memo No. 83-9, prepared for San Francisco District and South Pacific Division by the Hydrologic Engineering Center.

US Army Corps of Engineers and State of California, The Resources Agency (Department of Boating and Waterways), Coastal Data Information Program, 1982, 1983, and 1984 (monthly reports).

US Army Engineer District, San Francisco. 1982 (May). "Fisherman's Wharf Area, San Francisco Harbor, California," Information Pamphlet, General Design Conference, San Francisco, Calif.

Vincent, C. L., and Lockhart, J. H., Jr. 1983 (Sep). "Determining Sheltered Water Wave Characteristics," ETL 1110-2-305, Department of the Navy, Office of the Chief of Engineers, Washington, DC.

Wilson, B. W. 1967 (Nov). "Elastic Characteristics of Moorings," Journal, Waterways and Harbor Division, American Society of Civil Engineers, Vol 93, No. WW4, pp 27-56.

Table 1

Wave Heights for Existing Conditions

Direction	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
							0.0-ft swl										
NE	3.6	2.0	1.2	1.0	1.1	1.0	0.3	1.0	1.1	0.9	1.2	0.3	0.2	0.1	0.1	0.1	0.1
	3.9	3.3	3.8	3.8	3.3	3.6	0.6	3.2	3.2	2.1	3.1	0.9	0.2	0.2	0.1	0.2	0.1
NNE	3.6	2.5	1.8	1.7	1.8	1.3	1.2	0.7	0.6	1.3	1.4	1.2	0.8	0.2	0.2	0.2	0.1
	4.2	4.8	4.6	3.4	3.8	4.5	2.1	3.2	3.0	2.2	3.4	3.1	0.3	0.2	0.3	0.5	0.5
	4.9	5.8	4.3	4.7	4.8	3.1	4.6	2.0	3.9	4.6	3.9	3.6	1.6	0.9	1.0	1.0	1.3
N	3.6	2.0	1.4	1.4	1.5	0.8	0.7	0.5	2.0	1.5	1.3	1.5	0.4	0.2	0.1	0.3	0.1
	3.6	3.1	2.9	2.9	3.0	2.5	3.3	2.5	2.4	3.3	3.7	2.3	1.8	0.4	0.2	0.2	0.2
	3.7	3.8	3.6	4.4	3.8	3.1	2.8	1.4	4.8	3.2	3.3	2.6	2.2	0.3	0.3	0.3	0.1
NNW	3.6	2.0	1.0	1.2	0.9	0.9	0.7	0.5	1.3	1.3	1.1	0.8	1.0	0.4	0.5	0.3	0.1
	3.6	3.3	3.6	2.2	4.0	2.8	3.1	2.3	2.6	2.3	3.1	1.9	2.4	0.6	0.3	0.4	0.3
	3.6	3.8	3.9	2.9	4.3	3.4	3.3	2.7	2.9	2.4	2.6	2.8	3.5	0.5	0.5	0.4	0.4
NW	3.6	2.0	2.4	1.4	1.3	1.1	1.7	0.5	0.9	0.8	1.0	1.4	1.1	0.3	0.4	0.3	0.5
	3.7	3.5	4.6	3.6	3.4	2.9	2.5	0.8	2.0	2.0	2.2	2.8	3.2	0.5	2.0	0.6	0.8
	3.8	4.1	3.7	3.9	3.7	3.8	3.4	2.4	3.0	2.1	2.3	3.5	1.8	1.7	2.3	1.6	2.1
WNW	3.6	2.0	1.0	0.9	1.0	1.1	0.8	0.2	0.5	0.8	0.5	0.3	0.3	0.2	0.4	0.9	0.7
	3.6	3.4	2.9	2.5	2.3	2.2	2.1	0.4	1.3	0.9	0.6	0.7	0.8	0.4	2.3	1.0	1.0
	10.0	2.0	2.2	1.5	1.4	0.5	1.7	1.1	1.1	0.9	1.3	0.3	0.6	0.2	0.6	0.4	0.3
	10.0	3.0	3.2	2.5	3.9	2.2	2.7	3.2	3.1	2.7	2.6	0.8	1.5	0.5	1.0	1.0	0.5
								+5.7 ft swl									
NE	3.6	2.0	1.6	1.4	1.4	1.5	0.3	1.6	1.6	1.4	2.2	0.3	0.1	0.1	0.1	0.1	0.1
	3.9	3.3	3.8	3.2	2.8	3.3	0.7	3.6	2.8	2.4	2.0	0.7	0.2	0.1	0.1	0.1	0.1
NNE	3.6	2.5	1.8	1.8	0.8	1.5	0.6	0.6	1.3	1.4	1.8	1.1	0.6	0.1	0.2	0.2	0.1
	4.2	4.8	4.4	3.8	3.4	3.6	2.1	3.7	3.1	3.8	3.0	2.7	1.8	0.3	0.2	0.2	0.2
	4.9	5.8	5.2	4.4	2.5	4.4	1.7	2.0	4.6	5.5	4.5	2.8	1.2	0.8	0.4	0.3	0.8

(Continued)

Table 1 (Concluded)

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
									+5.7 ft swl (Concluded)								
N	3.6	2.0	1.0	2.2	1.7	1.2	1.2	0.6	1.5	1.8	1.6	0.7	1.4	0.2	0.3	0.2	0.1
	3.6	3.1	3.2	3.3	1.9	2.9	1.6	2.2	2.7	3.0	2.6	4.1	2.2	0.4	0.3	0.4	0.2
	3.7	3.8	3.6	3.3	4.4	4.1	1.8	1.4	3.5	3.5	4.4	2.1	1.3	0.3	0.4	0.2	0.3
NNW	3.6	2.0	2.0	1.7	1.2	0.5	1.3	0.9	1.1	1.0	1.0	1.5	1.9	0.5	0.2	0.2	0.1
	3.6	3.3	3.0	2.6	2.4	2.5	2.9	1.8	2.5	2.2	2.4	3.6	2.0	0.5	0.4	0.6	0.2
	3.6	3.8	3.1	2.5	2.8	2.8	3.3	1.9	2.4	2.7	1.8	3.3	1.2	0.7	0.8	0.7	0.2
NW	3.6	2.0	1.9	1.4	1.8	1.1	1.6	0.5	0.8	1.0	1.0	0.8	0.6	0.5	1.2	0.7	0.6
	3.7	3.5	2.4	2.9	3.9	2.8	3.2	1.1	2.2	2.1	1.2	2.8	0.8	1.1	1.9	0.8	1.6
	3.8	4.1	3.9	4.0	3.8	3.8	3.5	3.4	2.9	2.2	3.3	3.0	2.0	1.1	1.9	1.0	2.7
WNW	3.6	2.0	1.5	1.6	1.1	1.1	0.9	0.3	0.4	0.7	0.2	0.4	0.3	0.2	0.7	0.8	1.0
	3.6	3.4	3.6	3.0	2.7	2.0	2.4	0.5	1.2	1.1	0.6	0.7	0.2	0.4	1.9	1.4	1.3
	10.0	2.0	1.9	1.7	0.9	0.7	1.9	1.2	3.1	1.8	2.1	1.7	1.8	1.4	1.9	0.5	1.5
	10.0	3.0	3.5	2.9	4.1	2.4	2.7	3.0	3.5	3.3	2.1	3.0	2.7	1.3	2.1	0.7	2.1

Table 2

Wave Heights for Plan 1

Direction	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
								0.0-ft swl									
NE	3.6	2.0	1.3	1.2	1.1	0.6	0.5	1.4	0.9	0.8	0.5	0.5	0.3	0.1	0.2	0.1	0.1
	3.9	3.3	3.5	2.3	4.7	1.0	1.2	1.4	1.5	1.6	1.2	1.2	0.2	0.1	0.3	0.2	0.2
NNE	3.6	2.5	1.3	0.9	0.1	1.1	1.2	0.3	0.8	0.9	1.2	0.8	0.5	0.1	0.2	0.1	0.1
	4.9	5.8	4.0	4.4	0.4	3.3	3.2	1.8	2.0	3.4	2.5	1.7	0.4	0.5	0.9	0.9	1.2
N	3.6	2.0	0.4	1.2	0.2	0.8	0.4	0.2	0.5	0.2	0.3	0.5	0.5	0.1	0.1	0.1	0.1
	3.7	3.8	0.8	3.8	0.9	1.5	0.9	0.6	0.9	0.7	1.0	1.0	1.0	0.2	0.4	0.1	0.2
NNW	3.6	2.0	0.5	1.8	0.7	0.3	0.3	0.6	0.2	0.4	0.4	0.3	0.3	0.1	0.1	0.1	0.1
	3.6	3.8	1.5	3.8	1.2	1.0	1.0	1.3	0.7	0.4	1.0	0.9	0.6	0.1	0.3	0.2	0.1
NW	3.6	2.0	0.7	0.5	0.1	0.4	0.2	0.1	0.1	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1
	3.7	3.5	0.9	3.5	0.9	1.0	0.7	0.3	0.3	0.5	0.8	0.3	0.2	0.1	0.2	0.1	0.2
WNW	3.6	2.0	0.2	0.7	0.2	0.2	0.1	0.2	0.2	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.1
	3.6	3.4	0.3	1.8	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.1	0.1	0.1	0.1	0.1
	10.0	2.0	0.4	2.0	0.4	0.5	0.8	0.7	0.7	0.7	1.0	0.3	0.3	0.4	0.2	0.9	0.3
								+5.7 ft swl									
NE	3.6	2.0	1.2	1.3	2.5	0.7	0.6	1.1	0.7	0.6	0.5	0.5	0.1	0.1	0.3	0.1	0.1
	3.9	3.3	3.7	2.5	4.3	1.7	1.0	3.1	2.7	1.5	2.2	0.5	0.6	0.3	0.4	0.3	0.6
NNE	3.6	2.5	1.0	1.4	0.5	0.7	1.1	0.2	0.8	1.1	1.0	1.0	0.3	0.1	0.2	0.1	0.1
	4.9	5.8	3.5	4.1	0.9	3.3	0.9	1.7	1.8	3.7	1.9	1.3	1.2	0.3	0.5	0.3	0.7
N	3.6	2.0	0.5	0.9	0.2	0.5	0.7	0.3	0.4	0.7	0.3	0.8	0.3	0.1	0.1	0.1	0.1
	3.7	3.8	1.3	2.2	0.5	1.3	1.1	0.5	0.5	1.4	0.7	1.0	0.4	0.2	0.2	0.2	0.1
NNW	3.6	2.0	0.4	1.8	0.7	0.4	0.4	0.2	0.2	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.1
	3.6	3.8	0.7	3.8	0.8	0.7	0.5	0.5	0.5	0.3	0.4	0.6	0.2	0.1	0.2	0.1	0.1
NW	3.6	2.0	0.3	1.4	0.2	0.3	0.1	0.1	0.2	0.3	0.2	0.3	0.1	0.1	0.1	0.1	0.1
	3.7	3.5	0.5	2.7	0.3	0.6	0.6	0.1	0.3	0.3	0.4	0.1	0.2	0.1	0.1	0.3	0.1
WNW	3.6	2.0	0.2	0.6	0.1	0.1	0.2	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1
	3.6	3.4	0.4	1.6	0.3	0.1	0.3	0.1	0.4	0.2	0.6	0.2	0.1	0.1	0.2	0.3	0.1
	10.0	2.0	0.6	2.0	0.4	0.8	1.1	1.4	1.2	1.0	1.0	0.6	1.0	0.6	1.0	0.4	0.6

Table 3

Wave Heights for Plans 2-5 for Test Waves from West-Northwest, +5.7 ft swl

	Test Wave		Wave Height, ft														
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
2	10.0	2.0	0.7	1.9	0.4	0.8	1.2	1.4	1.0	0.9	1.0	0.5	1.0	0.4	0.9	0.3	0.6
3	10.0	2.0	0.7	1.9	0.4	1.1	0.8	1.2	1.2	0.8	1.3	0.6	1.0	0.3	0.8	0.4	0.9
4	10.0	2.0	0.8	2.0	0.4	0.8	0.7	1.0	0.9	1.0	1.0	0.6	0.8	0.3	0.6	0.3	0.7
5	10.0	2.0	0.8	1.9	0.5	0.7	1.2	1.6	1.0	0.9	0.8	0.5	1.0	0.4	0.9	0.2	0.6

Table 4

Wave Heights for Plans 6-10 for Test Waves from Northeast, +5.7 ft swl

	Test Wave		Wave Height, ft														
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
6	3.9	3.3	2.6	2.8	4.1	1.5	0.7	2.3	1.9	1.3	1.8	0.6	0.4	0.2	0.2	0.2	0.5
7	3.9	3.3	2.6	3.0	1.6	1.8	0.7	1.2	1.2	0.9	1.3	0.5	0.5	0.1	0.3	0.3	0.5
8	3.9	3.3	2.0	1.8	1.1	1.3	0.6	1.2	1.0	1.2	1.2	0.4	0.3	0.2	0.2	0.1	0.2
9	3.9	3.3	0.6	2.3	0.4	1.2	0.9	0.6	0.7	0.3	1.0	0.8	0.2	0.2	0.2	0.1	0.2
10	3.9	3.3	1.0	3.1	0.8	2.4	0.8	1.1	1.9	2.1	2.0	0.4	0.2	0.2	0.1	0.2	0.2

Table 5

Wave Heights for Plans 11-20 for Test Waves from Northeast, +5.7 ft swl

	Test Wave		Wave Height, ft														
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
11	3.9	3.3	0.8	2.5	1.4	1.8	0.5	1.3	1.7	0.6	1.7	0.7	0.3	0.1	0.1	0.1	0.2
12	3.9	3.3	0.8	2.6	0.9	1.2	0.5	0.6	0.9	1.1	1.2	1.2	0.3	0.2	0.3	0.1	0.2
13	3.9	3.3	1.2	2.4	0.8	1.0	0.3	0.9	1.1	0.9	1.1	0.9	0.3	0.2	0.3	0.1	0.1
14	3.9	3.3	1.3	2.5	0.7	0.5	0.4	1.0	0.7	0.4	0.4	0.3	0.2	0.1	0.2	0.1	0.1
15	3.9	3.3	1.2	2.0	1.0	0.3	0.6	0.6	1.0	0.8	0.6	0.7	0.4	0.2	0.1	0.1	0.2
16	3.9	3.3	2.1	2.5	1.2	0.8	0.5	0.8	0.6	0.6	0.5	0.5	0.3	0.1	0.2	0.1	0.2
17	3.9	3.3	1.3	1.9	0.7	0.6	0.3	0.9	0.4	0.2	0.5	0.2	0.2	0.1	0.1	0.1	0.2
18	3.9	3.3	1.3	1.9	0.8	1.4	0.4	1.0	1.1	0.8	1.4	0.5	0.3	0.1	0.2	0.2	0.2
19	3.9	3.3	1.2	1.6	0.4	1.0	0.4	0.8	0.5	0.4	1.0	0.4	0.3	0.1	0.2	0.1	0.2
20	3.9	3.3	1.2	2.0	0.9	1.1	0.4	0.9	0.6	0.3	0.7	0.7	0.4	0.1	0.2	0.1	0.2

Table 6

Wave Heights for Plans 21-33 for Test Waves from West-Northwest, +5.7 ft swl

	Test Wave		Wave Height, ft														
Plan	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
21	10.0	2.0	1.3	2.9	0.4	1.3	1.3	1.8	2.1	1.3	1.7	0.5	1.0	0.8	0.9	0.6	1.0
22	10.0	2.0	1.3	2.7	0.8	1.1	1.1	1.8	1.7	1.0	1.2	0.6	0.6	0.6	0.8	0.5	0.4
23	10.0	2.0	1.6	3.2	1.0	0.4	0.8	1.5	1.4	1.0	0.9	0.7	0.3	0.5	0.5	0.3	0.5
23	10.0	3.0	1.9	4.3	1.8	0.7	1.0	1.1	1.7	1.6	2.0	1.3	0.5	0.9	0.8	0.4	0.6
24	10.0	3.0	1.5	3.8	1.7	1.0	0.9	1.0	2.0	1.6	2.1	1.2	0.9	0.7	0.7	0.5	0.7
25	10.0	3.0	1.5	4.0	0.9	0.7	1.1	1.0	1.7	2.0	1.4	1.2	0.7	0.6	0.6	0.5	0.5
26	10.0	3.0	1.6	4.0	1.1	0.6	1.1	0.8	1.8	1.7	0.7	1.1	0.5	0.6	0.6	0.5	0.6
27	10.0	3.0	1.5	3.3	1.1	0.6	1.0	1.1	1.6	1.7	0.6	1.0	0.6	0.6	0.6	0.4	0.6
28	10.0	3.0	1.2	4.0	1.2	0.6	0.6	1.0	1.4	0.7	1.1	0.6	0.7	0.5	0.4	0.2	0.8
29	10.0	3.0	1.2	4.1	0.6	0.6	1.0	0.8	1.4	1.2	0.8	0.7	0.7	0.4	0.3	0.2	0.7
30	10.0	3.0	1.3	4.4	0.9	0.5	0.9	0.7	1.5	1.2	0.7	0.8	0.8	0.6	0.5	0.2	0.6
31	10.0	3.0	1.2	4.5	1.1	0.7	0.6	0.8	1.5	1.1	1.1	0.7	0.8	0.5	0.6	0.2	0.6
32	10.0	3.0	1.2	4.7	0.9	0.4	0.6	0.8	1.3	0.9	0.9	0.7	0.6	0.4	0.7	0.2	0.7
33	10.0	3.0	1.5	4.7	1.1	0.6	0.9	1.1	1.2	1.4	1.1	0.7	0.8	0.4	0.4	0.3	0.6

Table 7

Wave Heights for Plan 23 and Plans 34-39 for 3.9-sec, 3.3-ft-Test Waves from Northeast

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
								0.0-ft swl									
38	3.9	3.3	1.5	3.0	0.3	0.5	0.6	0.6	1.2	0.4	0.6	0.3	0.1	0.1	0.4	0.1	0.2
39	3.9	3.3	1.3	2.9	0.3	1.4	0.5	1.0	1.1	0.8	1.1	0.7	0.1	0.1	0.2	0.1	0.1
								+5.7 ft swl									
23	3.9	3.3	1.0	3.4	1.4	2.2	0.4	1.3	2.4	2.7	3.1	0.6	0.2	0.3	0.4	0.1	0.2
34	3.9	3.3	1.8	3.2	0.9	2.5	0.4	1.1	2.2	1.0	2.4	0.5	0.2	0.1	0.3	0.1	0.2
35	3.9	3.3	1.9	3.2	0.9	0.9	1.3	1.5	1.2	0.7	0.4	0.5	0.2	0.1	0.3	0.2	0.3
36	3.9	3.3	2.2	3.3	1.3	1.9	1.4	1.6	1.0	1.8	1.1	0.9	0.3	0.3	0.5	0.2	0.4
37	3.9	3.3	2.5	3.0	1.1	0.8	0.4	1.6	1.1	0.4	0.4	0.3	0.3	0.2	0.3	0.1	0.2
38	3.9	3.3	1.8	2.9	1.0	0.7	0.8	1.5	0.8	0.9	0.5	0.7	0.3	0.1	0.6	0.2	0.2
39	3.9	3.3	2.0	2.8	0.8	1.0	0.7	1.4	0.9	1.0	1.1	0.9	0.4	0.1	0.4	0.2	0.3

Table 8

Wave Heights for Plan 38

Direction	Test Wave Period sec	Test Wave Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
									0.0-ft swl								
NE	3.6	2.0	0.3	0.7	0.1	0.2	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
	3.9	3.3	1.5	3.0	0.3	0.5	0.6	0.6	1.2	0.4	0.6	0.3	0.1	0.1	0.4	0.1	0.2
NNE	3.6	2.5	0.2	1.2	0.1	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
	4.2	4.8	0.4	2.3	0.2	0.3	0.4	0.2	0.3	0.4	0.3	0.9	0.4	0.1	0.1	0.2	0.3
N	3.6	2.0	0.3	0.8	0.1	0.6	0.4	0.1	0.4	0.2	0.1	0.3	0.1	0.1	0.1	0.1	0.1
	3.6	3.1	0.2	1.6	0.1	0.9	0.4	0.2	0.6	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.1
NNW	3.6	2.0	0.6	1.1	0.2	0.5	0.3	0.3	0.1	0.2	0.3	0.4	0.1	0.1	0.1	0.1	0.1
	3.6	3.3	1.0	2.0	0.5	1.0	0.4	0.6	0.3	0.2	0.2	0.2	0.5	0.1	0.1	0.1	0.1
NW	3.6	2.0	0.3	1.5	0.1	0.1	0.1	0.2	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	3.8	4.1	0.6	2.5	1.0	0.5	0.3	0.4	0.4	1.0	0.8	0.4	0.1	0.1	0.4	0.1	0.1
WNW	3.6	2.0	0.3	0.5	0.1	0.2	0.2	0.2	0.3	0.6	0.2	0.1	0.1	0.1	0.2	0.1	0.1
	3.6	3.4	0.7	0.8	0.3	0.6	0.5	0.4	0.5	0.4	0.7	0.1	0.1	0.1	0.2	0.2	0.2
	10.0	2.0	0.7	2.3	0.3	0.7	0.5	0.9	0.4	0.3	0.6	0.3	1.0	0.3	0.6	0.7	0.3
	10.0	2.5	0.6	2.5	0.3	0.8	0.6	0.8	0.6	0.2	0.8	0.4	1.1	0.4	0.6	0.8	0.4
	10.0	3.0	0.9	2.6	0.4	0.8	0.6	1.1	0.5	0.4	0.6	0.4	1.1	0.3	0.7	0.9	0.4
									+5.7 ft swl								
NE	3.6	2.0	0.6	1.3	0.5	0.2	0.3	0.2	0.4	0.2	0.2	0.3	0.2	0.1	0.1	0.1	0.1
	3.9	3.3	1.8	2.9	1.0	0.7	0.8	1.5	0.8	0.9	0.5	0.7	0.3	0.1	0.6	0.2	0.2
NNE	3.6	2.5	0.3	1.6	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.1	0.1	0.1
	4.2	4.8	0.8	2.2	0.1	0.8	0.6	0.1	0.4	1.0	0.8	0.4	0.7	0.1	0.3	0.2	0.2
N	3.6	2.0	0.4	1.2	0.1	0.2	0.5	0.1	0.2	0.2	0.2	0.5	0.5	0.1	0.1	0.1	0.1
	3.6	3.1	0.4	5.0	0.3	0.6	0.4	0.2	0.3	0.2	0.3	0.4	0.6	0.2	0.2	0.1	0.1
NNW	3.6	2.0	0.3	0.8	0.2	0.4	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	3.6	3.3	0.3	1.7	0.3	0.3	0.2	0.1	0.2	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1

(Continued)

Table 8 (Concluded)

	Test Wave		Wave Height, ft														
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
+5.7 ft swl (Concluded)																	
NW	3.6	2.0	0.1	2.7	0.2	0.1	0.1	0.1	0.2	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1
	3.8	4.1	0.2	5.7	0.2	0.2	0.3	0.7	0.5	0.9	0.7	0.2	0.1	0.1	0.1	0.1	0.1
WNW	3.6	2.0	0.1	0.3	0.1	0.2	0.1	0.1	0.2	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1
	3.6	3.4	0.1	1.3	0.2	0.5	0.2	0.4	0.5	0.3	0.5	0.2	0.1	0.1	0.2	0.3	0.1
	10.0	2.0	1.0	1.9	1.0	1.0	0.6	0.9	1.2	1.3	1.1	0.7	0.3	0.4	0.4	0.3	0.5
	10.0	2.5	1.3	2.3	1.4	0.9	0.7	1.0	1.6	1.8	1.5	0.9	0.4	0.5	0.5	0.3	0.5
	10.0	3.0	1.5	2.6	1.8	1.0	0.6	1.1	1.5	2.2	1.8	1.1	0.5	0.6	0.5	0.4	0.6

Table 9

Wave Heights for Plan 40 for Test Waves from West-Northwest

Test Wave		Wave Height, ft														
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
							0.0-ft swl									
10.0	2.5	0.7	2.5	0.4	0.7	0.6	0.7	0.5	0.2	0.6	0.4	1.0	0.4	0.5	0.7	0.3
							+5.7 ft swl									
10.0	2.5	1.2	2.3	1.4	1.0	0.5	1.0	1.5	1.8	1.5	0.9	0.5	0.4	0.5	0.4	0.5

Table 10

Wave Heights for Plans 38 and 39 at Various Locations near the Harbor Entrance for Test Waves from Northeast

Plan	Test Wave Period sec	Test Wave Height ft	Wave Height, ft Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A
			0.0-ft swl						
38	3.6	2.0	2.3	2.4	2.5	0.4	1.2	0.5	1.0
38	3.9	3.3	5.1	3.9	8.8	1.7	1.7	4.4	2.5
39	3.6	2.0	2.4	2.4	2.9	0.8	1.7	0.9	1.8
39	3.9	3.3	5.6	3.6	8.4	1.6	1.8	4.1	2.7
			+5.7 ft swl						
38	3.6	2.0	2.5	1.5	2.9	0.4	1.3	0.4	1.0
38	3.9	3.3	5.1	4.3	9.2	2.3	2.2	8.9	3.4
39	3.6	2.0	2.7	2.5	2.5	0.6	1.7	0.6	2.8
39	3.9	3.3	5.5	4.2	9.1	2.1	1.4	7.2	2.8

Table 11

Wave Heights for Plans 41-46 for 3.9-sec, 3.3-ft Test Waves from Northeast

	Wave Height, ft																				
Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
										0.0-ft swl												
41	4.5	2.8	3.4	1.6	1.0	2.1	1.4	0.9	1.8	0.4	0.6	0.7	0.8	0.6	0.4	1.1	0.3	0.4	0.1	0.3	0.1	0.1
42	3.3	1.3	3.2	0.6	1.6	1.0	0.9	0.5	1.8	0.3	1.2	0.6	0.9	0.9	1.1	1.2	0.3	0.2	0.1	0.1	0.1	0.1
43	3.0	2.8	3.6	1.0	1.0	3.6	2.9	1.0	1.6	0.3	1.3	0.5	0.7	0.7	0.3	1.5	0.4	0.2	0.1	0.1	0.1	0.1
44	3.5	3.7	5.3	1.5	3.2	3.3	2.5	1.3	1.4	0.4	1.3	0.3	0.6	0.8	0.4	1.0	0.7	0.4	0.1	0.1	0.1	0.1
45	3.5	2.6	4.2	1.0	1.3	4.6	4.3	0.8	1.6	0.4	0.9	0.3	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1
46	4.2	3.5	4.4	0.8	2.5	1.7	4.2	0.6	1.3	0.7	0.5	0.8	1.3	0.8	0.7	1.4	0.1	0.2	0.1	0.1	0.1	0.1
										+5.7 ft swl												
41	4.5	1.8	3.3	1.5	1.5	2.4	0.6	0.8	1.6	0.5	0.9	0.6	0.6	0.9	0.8	0.7	0.6	0.2	0.1	0.1	0.1	0.1
42	3.8	2.9	3.1	1.4	2.4	0.9	0.6	1.2	1.5	0.6	1.6	0.3	0.8	1.5	1.1	0.5	0.6	0.2	0.1	0.1	0.1	0.1
43	4.1	2.8	3.4	1.6	1.4	3.1	3.2	1.0	1.6	0.5	1.3	0.4	1.0	1.1	1.3	1.2	0.4	0.2	0.1	0.3	0.1	0.1
44	4.2	1.7	4.8	1.9	1.2	2.5	0.9	1.3	2.2	0.5	0.8	0.9	0.2	0.5	0.7	0.5	0.4	0.7	0.1	0.2	0.1	0.1
45	4.1	1.9	3.8	1.5	1.3	4.9	2.6	1.0	1.8	0.8	0.7	0.4	0.9	0.6	0.3	0.3	0.2	0.2	0.1	0.2	0.1	0.1
46	3.3	2.6	3.7	1.0	2.2	1.5	4.7	1.2	1.7	0.5	0.9	0.7	0.7	0.8	0.3	0.9	0.4	0.3	0.1	0.1	0.1	0.1

Table 12

Wave Heights for Plan 41 and Plans 45-51 for 4.2-sec, 4.8-ft Test Waves from North-Northeast

	Wave Height, ft																					
Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
										0.0-ft swl												
41	3.3	5.2	3.6	0.5	2.2	2.2	0.9	1.0	3.3	0.4	1.0	1.1	0.5	0.8	1.0	1.0	1.7	0.7	0.2	0.3	0.4	0.5
45	3.6	4.9	3.8	0.6	0.8	2.9	2.1	0.5	3.3	0.1	0.3	0.6	0.4	0.3	0.4	0.3	0.7	0.4	0.2	0.3	0.4	0.5
46	3.5	4.7	3.5	0.7	1.4	2.1	7.1	0.7	3.4	0.6	1.2	1.4	0.4	0.9	1.3	0.9	2.0	0.6	0.2	0.3	0.4	0.5
47	3.8	4.7	3.2	0.8	1.7	3.3	2.3	0.9	3.8	0.4	0.3	2.0	0.2	0.2	0.3	0.5	1.5	0.4	0.1	0.2	0.2	0.3
48	3.6	4.7	2.9	0.8	1.1	2.4	0.7	0.2	2.7	0.5	0.3	0.4	0.6	0.4	0.2	0.5	1.1	0.5	0.2	0.3	0.2	0.2
49	3.2	5.1	3.1	0.8	1.8	2.5	0.7	0.2	3.4	0.4	0.7	0.6	0.4	0.3	0.5	0.3	1.4	0.5	0.2	0.2	0.2	0.2
50	2.2	5.1	2.1	0.7	1.9	4.5	1.8	0.7	3.3	0.2	0.2	0.7	0.3	0.5	0.2	0.2	0.3	0.2	0.1	0.5	0.2	0.2
51	4.1	3.6	3.4	1.0	1.2	2.1	5.8	0.4	3.0	0.2	0.4	0.3	0.2	0.3	0.2	0.4	1.2	0.4	0.1	0.2	0.1	0.2
										+5.7 ft swl												
41	3.2	4.3	2.3	0.8	1.8	2.0	0.6	0.9	2.7	0.6	0.4	0.6	0.5	0.4	0.4	1.1	0.9	0.3	0.1	0.1	0.1	0.1
45	3.7	5.1	3.9	1.3	1.5	4.2	3.9	0.7	2.8	0.7	0.7	0.5	0.3	0.4	0.5	0.4	0.3	0.3	0.1	0.2	0.3	0.3
46	2.9	3.2	2.7	0.2	0.7	1.2	4.6	0.5	2.5	0.2	0.9	0.8	0.3	0.6	0.8	1.0	0.7	0.6	0.1	0.2	0.1	0.3
47	4.1	3.7	4.0	0.8	2.5	3.3	2.4	1.1	3.0	0.7	0.8	1.5	0.6	0.5	0.4	0.7	1.5	0.4	0.2	0.2	0.1	0.3
48	3.1	3.5	2.8	0.5	1.5	1.7	0.6	0.4	3.2	0.4	0.6	0.5	0.4	0.5	0.8	0.6	0.9	0.6	0.1	0.2	0.2	0.2
49	2.8	3.6	2.6	0.5	2.1	1.7	0.5	0.8	3.1	0.4	0.4	0.7	0.5	0.4	0.7	0.9	0.9	0.7	0.1	0.2	0.1	0.2
50	2.7	4.2	2.9	0.7	1.5	2.6	2.0	0.4	3.0	0.5	0.3	0.5	0.3	0.6	0.4	0.5	0.3	0.4	0.1	0.1	0.2	0.2
51	3.0	3.1	3.0	0.2	1.0	1.3	4.8	0.5	3.1	0.5	0.8	0.3	0.5	0.2	1.0	0.7	0.6	0.3	0.1	0.1	0.1	0.2

Table 13

Wave Heights for Plans 48-51 for 3.9-sec, 3.3-ft Test Waves from Northeast

Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
	Wave Height, ft																					
										0.0-ft swl												
48	3.5	5.4	4.0	1.3	2.0	2.7	0.5	1.1	1.7	0.5	1.2	0.3	0.7	0.8	0.7	1.2	0.3	0.1	0.1	0.1	0.1	0.1
49	3.4	3.9	3.0	1.1	0.7	2.3	0.5	0.8	1.5	0.4	0.3	0.3	0.4	0.2	0.5	0.6	0.2	0.1	0.1	0.1	0.1	0.1
50	3.3	3.9	2.9	1.0	1.0	5.2	1.1	0.8	1.9	0.5	0.3	0.1	0.5	0.4	0.4	0.1	0.2	0.1	0.1	0.1	0.1	0.1
51	4.2	4.3	3.4	1.2	2.2	1.3	5.5	1.0	2.3	0.6	0.9	0.2	0.7	0.5	0.7	1.0	0.1	0.1	0.1	0.1	0.1	0.1
										+5.7 ft swl												
48	3.0	4.1	3.2	1.2	1.8	1.4	0.5	1.1	2.1	0.4	1.0	0.1	0.8	0.8	0.8	0.7	0.2	0.1	0.1	0.1	0.1	0.1
49	3.6	3.9	3.1	1.3	1.4	1.6	0.2	0.7	2.0	0.3	0.5	0.4	0.6	0.5	0.1	0.4	0.2	0.1	0.1	0.1	0.1	0.1
50	3.8	4.8	3.9	1.1	1.9	4.0	1.5	0.8	1.8	0.8	0.5	0.4	0.4	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
51	2.8	3.9	3.1	0.8	2.2	1.1	3.0	0.5	2.1	0.3	0.7	0.1	0.8	0.6	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.1

Table 14

Wave Heights for Plans 52-59 for 3.9-sec, 3.3-ft Test Waves from Northeast

	Wave Height, ft																				
Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
										0.0-ft swl												
52	3.9	2.7	3.3	1.0	2.5	1.5	0.4	0.9	1.4	0.6	1.3	0.5	1.0	1.3	0.8	1.0	0.4	0.1	0.1	0.1	0.1	0.1
53	4.3	1.9	4.5	1.0	2.0	2.7	0.7	0.8	1.2	0.2	0.7	0.6	0.5	0.7	0.4	1.4	0.4	0.1	0.1	0.3	0.1	0.1
54	3.8	4.5	3.1	1.0	1.7	4.4	2.4	0.9	1.9	0.4	0.5	0.5	0.4	0.5	0.4	0.5	0.3	0.1	0.1	0.1	0.2	0.1
55	3.2	4.7	3.4	1.0	2.2	1.2	4.1	1.0	1.8	0.3	1.3	0.6	1.0	0.6	0.8	1.3	0.5	0.2	0.1	0.2	0.1	0.1
56	3.8	4.0	3.7	1.1	2.2	1.7	1.0	1.0	2.0	0.7	1.0	0.2	0.5	1.2	1.1	1.2	0.2	0.1	0.1	0.1	0.1	0.1
57	4.6	2.3	4.2	1.1	3.0	3.4	0.8	1.0	1.6	0.3	0.5	0.4	0.6	0.7	0.6	0.9	0.1	0.1	0.1	0.3	0.1	0.1
58	3.6	4.9	3.0	0.9	1.1	4.5	1.7	0.8	1.5	0.5	0.6	0.3	0.5	0.5	0.4	0.5	0.4	0.1	0.1	0.2	0.1	0.1
59	3.2	5.1	3.0	1.2	2.2	1.0	3.2	0.9	1.9	0.6	1.4	0.3	1.2	1.0	0.9	0.9	0.1	0.1	0.1	0.2	0.1	0.1
										+5.7 ft swl												
52	3.8	4.3	3.4	0.9	2.4	1.7	0.8	0.7	1.5	0.2	1.5	0.4	0.6	1.0	1.1	1.0	0.4	0.1	0.1	0.1	0.1	0.1
53	3.8	2.1	3.1	1.2	1.4	2.8	1.0	0.9	2.0	0.2	0.5	0.4	0.3	0.3	0.8	0.5	0.3	0.1	0.1	0.1	0.1	0.1
54	3.3	3.0	2.7	0.8	0.7	3.3	0.9	0.5	1.8	0.3	0.5	0.2	0.3	0.3	0.2	0.4	0.1	0.1	0.1	0.1	0.1	0.1
55	2.9	4.1	3.4	1.0	1.5	1.2	3.8	0.8	2.1	0.4	1.1	0.3	0.5	0.9	1.1	1.1	0.4	0.2	0.1	0.1	0.1	0.1
56	3.5	4.9	3.3	1.1	2.4	1.5	0.8	1.2	1.5	0.6	0.9	0.3	0.8	0.9	0.8	1.0	0.2	0.1	0.1	0.1	0.1	0.1
57	3.9	2.7	3.0	1.2	1.2	2.9	0.4	0.9	1.5	0.2	0.7	0.2	0.5	0.6	0.5	0.7	0.3	0.1	0.1	0.1	0.1	0.1
58	2.6	3.4	2.5	1.0	1.2	3.2	1.6	0.7	1.9	0.4	0.6	0.1	0.4	0.6	0.4	0.4	0.1	0.1	0.1	0.1	0.1	0.1
59	3.0	5.4	3.2	0.8	1.9	1.4	2.9	0.9	1.3	0.5	1.0	0.3	0.6	0.8	0.7	0.9	0.3	0.1	0.1	0.1	0.1	0.1

Table 15

Wave Heights for Plans 60-63 for 3.9-sec, 3.3-ft Test Waves from Northeast

	Wave Height, ft																					
Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
										0.0-ft swl												
60	5.9	4.2	4.5	1.0	1.6	5.3	1.7	0.8	2.1	0.3	0.9	0.6	0.5	0.4	0.6	0.5	0.4	0.3	0.1	0.2	0.2	0.2
61	5.6	4.6	4.2	1.0	1.9	6.3	1.7	0.9	2.0	0.3	1.0	0.5	0.8	0.7	1.0	0.6	0.3	0.2	0.1	0.5	0.3	0.2
62	4.7	4.5	3.5	0.8	2.0	4.7	2.6	0.9	2.3	0.3	0.7	0.4	0.4	0.4	0.5	0.6	0.4	0.3	0.1	0.2	0.2	0.1
63	3.7	4.6	3.3	0.9	1.5	5.4	1.3	0.8	1.5	0.4	0.5	0.3	0.5	0.5	0.6	0.3	0.3	0.1	0.1	0.1	0.1	0.1
										+5.7 ft swl												
60	3.8	4.5	2.7	0.7	1.2	5.4	2.0	0.8	1.5	0.2	0.5	0.2	0.5	0.3	0.3	0.4	0.2	0.1	0.1	0.1	0.1	0.1
61	4.0	4.5	3.1	0.9	1.0	5.2	2.2	0.7	2.1	0.3	0.6	0.2	0.4	0.3	0.4	0.5	0.2	0.1	0.1	0.1	0.1	0.1
62	3.8	1.8	3.9	0.8	1.7	3.4	3.1	0.7	2.1	0.3	0.6	0.1	0.4	0.4	0.6	0.3	0.1	0.1	0.1	0.1	0.1	0.1
63	3.5	2.8	3.2	0.7	1.4	4.3	2.0	0.8	1.7	0.3	0.4	0.2	0.6	0.2	0.5	0.4	0.2	0.1	0.1	0.1	0.1	0.1

Table 16

Wave Heights for Plans 53, 54, 56-58, and 60-63 for 4.2-sec, 4.8-ft Test Waves from North Northeast

	Wave Height, ft																					
Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
										0.0-ft swl												
53	3.7	6.0	4.2	0.6	2.3	2.2	1.1	0.7	4.5	0.5	0.9	1.4	0.8	1.1	1.4	1.1	2.6	0.6	0.4	0.2	0.5	0.8
54	3.0	5.4	3.9	0.9	1.5	3.5	3.9	0.2	4.5	0.4	0.3	1.0	0.4	0.2	0.3	0.2	1.3	0.6	0.3	0.5	0.5	0.7
56	4.0	5.2	4.0	0.7	1.4	2.6	1.2	0.8	4.5	0.9	0.3	1.3	0.9	1.6	0.7	0.7	2.1	0.8	0.4	1.0	0.5	0.9
57	3.4	5.1	3.1	1.2	2.0	2.4	1.4	0.2	3.9	0.7	1.0	1.2	0.2	0.8	1.3	0.5	2.2	0.5	0.3	0.5	0.4	0.5
58	3.1	4.3	4.0	0.8	1.4	3.5	1.7	0.2	4.3	0.3	0.3	0.6	0.4	0.2	0.1	0.1	0.7	0.2	0.1	0.3	0.2	0.3
60	4.1	3.8	2.8	0.6	2.0	3.7	1.8	0.7	4.0	0.2	0.2	0.7	0.4	0.3	0.2	0.2	0.5	0.2	0.1	0.2	0.2	0.3
61	4.5	4.8	2.6	0.6	2.0	3.6	1.9	0.6	4.2	0.3	0.4	0.8	0.4	0.3	0.4	0.3	0.8	0.5	0.1	0.2	0.2	0.2
62	2.7	4.9	3.4	0.5	1.3	2.0	3.5	0.5	3.5	0.2	0.3	1.0	0.4	0.2	0.4	0.4	1.3	0.5	0.2	0.3	0.3	0.3
63	3.7	4.6	3.3	0.9	1.5	4.1	1.4	0.8	4.1	0.4	0.3	0.3	0.5	0.5	0.6	0.4	0.9	0.4	0.2	0.5	0.4	0.5
										+5.7 ft swl												
53	3.0	4.1	2.1	0.4	0.9	1.8	0.7	0.3	3.6	0.4	0.5	1.1	0.7	0.6	0.6	0.5	1.2	1.2	0.2	0.2	0.3	0.2
54	3.5	4.1	3.0	0.6	1.1	2.6	3.5	0.4	4.1	0.4	0.6	0.8	0.4	0.4	0.6	0.4	0.7	0.6	0.1	0.3	0.2	0.3
56	3.2	5.1	2.5	0.9	1.2	2.1	0.5	0.2	2.8	0.3	1.1	0.5	0.5	0.8	0.8	0.9	1.0	0.9	0.2	0.3	0.2	0.2
57	3.3	4.4	2.6	0.5	1.7	2.1	0.7	0.6	4.8	0.4	0.9	1.3	0.9	0.9	0.7	0.4	1.1	1.3	0.2	0.1	0.2	0.2
58	2.8	4.5	2.9	0.6	1.5	2.4	2.6	0.3	2.7	0.6	0.4	0.5	0.3	0.2	0.3	0.3	0.4	0.5	0.1	0.1	0.1	0.4
60	2.8	3.5	2.9	0.6	1.1	2.8	3.2	0.4	2.0	0.3	0.5	0.7	0.3	0.4	0.4	0.1	0.5	0.5	0.1	0.2	0.2	0.3
61	3.1	4.6	3.2	0.4	1.4	3.0	2.6	0.6	2.6	0.6	0.6	0.8	0.2	0.2	0.6	0.3	0.8	0.5	0.2	0.1	0.1	0.3
62	3.3	4.7	3.4	0.4	1.2	3.2	4.7	0.8	3.6	0.7	0.7	0.9	0.4	0.3	0.6	0.5	0.8	0.9	0.3	0.4	0.3	0.5
63	3.1	3.9	3.5	0.9	1.4	2.8	2.2	0.4	2.9	0.5	0.5	0.7	0.[illegible]	0.5	0.5	0.7	0.6	0.5	0.1	0.2	0.2	0.2

Table 17

Wave Heights for Plans 64-75 for 4.2-sec, 4.8-ft Test Waves from North Northeast

Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
	Wave Height, ft																					
											0.0-ft swl											
64	2.6	3.4	1.3	0.6	2.0	2.5	2.8	0.8	2.4	0.4	0.6	0.3	0.6	0.2	0.3	0.4	0.9	0.1	0.1	0.1	0.1	0.2
65	2.5	3.3	3.6	2.0	3.2	3.8	0.9	0.5	2.0	0.3	0.6	0.3	0.4	0.5	0.6	0.8	0.6	0.1	0.1	0.1	0.1	0.2
66	2.5	3.5	2.9	2.7	2.8	4.5	1.6	1.5	2.4	0.6	0.7	0.4	0.4	0.6	0.3	0.9	0.8	0.1	0.1	0.1	0.1	0.2
67	3.5	3.9	1.1	0.8	3.5	4.8	5.3	1.0	3.2	0.7	0.7	1.2	0.5	0.5	0.4	0.6	2.1	0.4	0.3	0.6	0.4	0.8
68	3.6	4.7	5.4	3.0	4.1	5.8	2.3	1.3	2.3	0.5	1.5	1.0	1.0	1.5	1.0	1.1	1.7	0.5	0.3	0.6	0.6	0.7
69	3.8	6.4	4.7	4.7	4.0	6.9	1.9	1.8	2.9	0.7	1.8	0.9	0.7	1.6	1.2	1.7	1.6	0.5	0.2	0.4	0.3	0.4
70	4.1	4.1	2.2	1.0	4.1	4.5	2.4	1.3	2.7	0.9	0.5	0.7	0.8	0.3	0.1	0.3	1.2	0.2	0.1	0.3	0.2	0.4
71	3.8	5.2	4.9	2.2	4.5	6.3	2.9	1.0	3.2	0.7	0.8	0.7	1.1	1.2	0.8	1.0	1.6	0.4	0.2	0.4	0.4	0.6
72	3.9	4.5	3.7	2.8	4.4	6.4	3.7	1.6	3.3	0.9	0.9	1.0	0.2	0.7	0.8	1.5	1.7	0.2	0.2	0.6	0.5	0.9
73	3.9	3.6	2.5	0.6	4.5	4.8	1.9	1.4	2.8	0.9	0.7	0.6	0.8	0.4	0.6	0.6	1.1	0.2	0.2	0.5	0.4	0.7
74	3.4	4.5	3.4	1.8	4.2	5.9	2.7	1.2	3.0	0.9	0.6	0.6	0.7	0.5	0.3	0.9	1.4	0.1	0.1	0.4	0.3	0.7
75	4.1	4.8	3.9	3.3	4.1	6.7	2.4	1.8	3.3	1.1	1.0	0.9	0.7	0.6	0.7	1.6	1.3	0.1	0.2	0.4	0.4	0.8
											+5.7 ft swl											
64	2.4	3.0	1.3	1.0	2.4	3.3	0.9	1.1	2.3	0.5	0.3	0.5	0.3	0.2	0.1	0.4	0.2	0.3	0.1	0.2	0.1	0.1
65	1.7	3.3	2.7	1.3	2.2	3.3	1.2	0.3	1.6	0.3	0.5	0.4	0.3	0.5	0.4	0.4	0.4	0.3	0.1	0.1	0.1	0.1
66	1.7	3.3	2.6	2.1	2.3	3.1	1.7	0.6	1.4	0.3	0.8	0.5	0.3	0.6	0.4	0.6	0.6	0.3	0.1	0.1	0.1	0.2
67	2.6	2.9	1.4	0.8	2.5	3.3	1.7	0.7	1.7	0.7	0.5	0.4	0.2	0.1	0.1	0.6	0.4	0.4	0.1	0.1	0.2	0.2
68	2.1	3.5	2.5	1.4	2.5	3.4	1.3	0.7	1.4	0.5	0.4	0.4	0.3	0.5	0.4	0.8	0.3	0.4	0.1	0.1	0.1	0.1
69	2.1	3.5	3.1	2.6	3.1	3.9	1.8	1.1	1.9	0.3	1.0	0.4	0.6	0.8	0.7	0.9	0.5	0.2	0.1	0.1	0.2	0.2
70	3.0	3.9	1.8	1.1	3.0	4.5	1.8	0.8	1.9	0.7	0.4	0.5	0.5	0.4	0.2	0.7	0.2	0.4	0.1	0.2	0.3	0.4
71	2.8	3.3	3.4	1.6	3.1	3.4	0.8	1.1	1.6	0.7	0.6	0.3	0.5	0.8	0.6	1.0	0.3	0.3	0.1	0.1	0.2	0.2
72	2.3	3.1	2.9	2.4	2.9	3.8	2.5	0.9	2.2	0.4	0.8	0.2	0.3	0.4	0.8	0.6	0.5	0.2	0.1	0.2	0.2	0.3
73	3.1	4.1	1.1	0.7	2.7	4.7	4.5	0.3	3.7	0.6	0.3	0.9	0.5	0.3	0.6	0.9	0.8	0.7	0.2	0.3	0.3	0.7
74	3.1	3.9	3.6	1.8	3.2	5.2	3.9	1.1	3.4	0.2	0.8	0.9	0.6	0.6	0.7	0.8	0.5	0.6	0.1	0.3	0.3	0.3
75	2.5	4.4	3.6	3.3	3.9	5.3	2.7	1.3	3.9	0.3	1.6	0.6	0.4	1.0	1.4	1.2	0.5	0.2	0.1	0.1	0.4	0.7

Table 18

Wave Heights for Plans 64-75 for 3.9-sec, 3.3-ft Test Waves from Northeast, 0.0-ft swl

	Wave Height, ft																					
Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
64	5.8	2.8	4.5	1.8	2.9	2.9	1.9	1.7	3.7	1.1	1.9	0.6	0.9	0.8	1.2	0.9	0.5	0.2	0.1	0.5	0.3	0.2
65	3.8	4.4	3.7	2.9	2.1	3.7	3.2	2.4	2.7	0.9	0.9	1.1	0.9	1.3	0.9	1.8	0.6	0.2	0.1	0.3	0.3	0.1
66	4.6	4.0	6.1	5.3	3.3	5.5	3.1	3.0	3.1	1.4	1.9	0.2	1.5	1.8	2.0	0.4	0.8	0.2	0.1	0.5	0.3	0.2
67	5.6	2.8	5.7	2.2	3.0	5.0	3.3	1.4	2.8	0.9	1.9	0.5	0.7	0.6	1.8	1.1	0.5	0.1	0.1	0.3	0.2	0.2
68	3.2	4.5	4.5	1.5	3.5	6.1	4.5	1.4	2.6	0.5	1.0	1.1	1.2	1.0	1.1	0.8	0.5	0.2	0.1	0.1	0.1	0.1
69	2.9	3.5	5.4	5.2	3.5	4.0	3.4	3.5	2.4	2.0	3.5	0.8	2.3	1.9	1.7	1.4	0.7	0.2	0.1	0.9	0.5	0.3
70	5.7	2.4	3.9	1.7	2.9	4.9	2.3	1.1	2.7	0.8	1.3	0.7	0.7	0.6	0.9	0.2	0.3	0.1	0.1	0.3	0.2	0.2
71	5.4	3.0	6.8	3.5	2.6	5.5	3.3	2.7	3.4	1.6	2.7	0.7	1.6	1.4	1.3	0.9	0.6	0.1	0.1	0.5	0.3	0.2
72	5.8	2.8	4.5	3.1	2.2	4.8	2.0	3.4	2.8	1.5	1.7	1.2	1.6	1.5	1.9	0.5	0.5	0.2	0.2	0.4	0.3	0.2
73	4.8	2.9	4.3	1.8	2.8	4.3	2.4	1.1	2.8	1.0	1.4	0.3	0.7	0.7	1.0	0.2	0.2	0.1	0.1	0.4	0.2	0.2
74	5.0	3.0	5.9	3.3	2.5	5.4	3.2	2.6	3.0	1.4	1.3	0.6	1.3	1.1	1.5	0.6	0.4	0.2	0.1	0.3	0.2	0.1
75	5.4	2.9	4.9	3.6	2.6	5.2	2.8	3.1	3.0	1.4	2.3	0.5	1.6	1.7	1.7	0.8	0.4	0.1	0.1	0.5	0.3	0.2

Table 19

Wave Heights for Plans 76-90 for 3.9-sec, 3.3-ft Test Waves from Northeast, 0.0-ft swl

	Wave Height, ft																					
Plan	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
76	4.3	4.8	1.9	1.0	1.9	4.9	4.0	1.5	2.4	0.8	0.7	0.5	0.7	0.6	1.0	0.2	0.3	0.1	0.1	0.2	0.1	0.1
77	4.4	4.0	2.4	1.8	3.2	3.0	3.5	1.3	1.9	1.0	0.9	0.5	0.7	0.9	1.3	0.6	0.5	0.1	0.1	0.3	0.1	0.1
78	3.8	3.9	2.0	1.0	2.0	4.4	3.9	1.0	2.0	0.6	0.5	0.3	0.7	0.7	0.9	0.8	0.1	0.1	0.1	0.1	0.1	0.1
79	4.4	4.2	1.1	1.6	1.4	3.0	2.9	0.9	2.5	0.8	1.3	0.8	0.6	0.3	0.9	1.3	0.4	0.1	0.1	0.2	0.1	0.1
80	4.3	3.7	2.0	1.3	2.0	3.8	3.1	1.4	2.5	0.8	0.8	0.4	0.8	0.5	1.4	0.9	0.5	0.1	0.1	0.2	0.1	0.1
81	3.6	4.0	1.5	0.9	1.7	4.3	3.2	1.1	2.2	0.7	1.1	0.5	0.5	0.6	1.3	1.3	0.5	0.1	0.1	0.2	0.1	0.1
82	4.1	4.4	2.1	1.5	2.3	4.5	2.2	1.5	1.6	1.0	0.9	0.2	0.4	0.3	0.9	0.3	0.3	0.1	0.1	0.2	0.1	0.1
83	2.8	4.7	2.1	0.8	2.3	6.4	3.0	1.6	2.3	0.4	0.9	0.5	0.4	0.3	0.9	0.7	0.3	0.1	0.1	0.2	0.1	0.1
84	4.3	4.2	1.4	0.7	2.3	5.5	2.6	0.8	2.0	0.4	0.4	0.2	0.6	0.3	1.1	0.7	0.1	0.1	0.1	0.1	0.1	0.1
85	3.8	5.0	2.0	1.4	2.3	5.2	2.0	1.1	2.6	1.2	1.8	0.4	0.9	1.1	1.3	0.6	0.3	0.1	0.1	0.3	0.1	0.1
86	4.1	4.8	2.1	1.3	2.4	3.8	1.5	1.2	1.9	1.2	1.2	0.8	1.1	0.9	1.2	0.4	0.2	0.1	0.1	0.2	0.1	0.1
87	4.1	3.5	1.6	1.0	3.4	1.0	0.7	1.3	3.2	0.9	1.3	0.3	1.3	1.0	1.0	0.9	0.2	0.1	0.1	0.2	0.1	0.1
88	5.9	4.0	2.8	1.3	1.0	6.2	4.2	0.7	1.8	0.9	1.0	0.4	0.7	0.7	0.9	0.5	0.2	0.1	0.1	0.2	0.1	0.1
89	4.0	5.4	1.9	1.6	2.8	4.0	3.1	1.2	2.5	0.7	1.1	0.6	1.2	1.3	1.1	0.6	0.6	0.1	0.1	0.2	0.1	0.1
90	4.2	4.1	1.8	1.1	2.4	3.3	1.1	0.6	2.4	0.5	1.8	0.5	0.9	0.7	1.7	1.1	0.7	0.2	0.1	0.2	0.2	0.1

Table 20

Wave Heights for Plans 78 for Test Waves from Northeast, North-Northeast, and North

Direction	Test Wave Period sec	Test Wave Height ft	Gage 1A	Gage 2A	Gage 3A	Gage 4A	Gage 5A	Gage 6A	Gage 7A	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15
											0.0-ft swl													
NE	3.6	2.0	1.0	1.1	0.6	0.3	0.4	0.7	1.6	0.3	0.5	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1
	3.9	3.3	3.8	3.9	2.0	1.0	2.0	4.4	3.9	1.0	2.0	0.6	0.5	0.3	0.7	0.7	0.9	0.8	0.1	0.1	0.1	0.1	0.1	0.1
NNE	3.6	2.5	1.5	1.8	0.8	0.1	0.7	2.5	1.4	0.6	0.5	0.1	0.1	0.8	0.3	0.2	0.2	0.4	0.6	0.3	0.1	0.1	0.1	0.1
	4.2	4.8	4.5	3.1	2.0	0.9	1.3	3.0	2.0	0.5	2.9	1.0	0.8	1.0	1.3	0.4	0.3	0.8	1.4	0.4	0.1	0.4	0.3	0.4
N	3.6	2.0	1.2	1.3	0.4	0.2	0.5	1.0	1.7	0.2	1.4	0.1	0.1	0.7	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.1
	3.6	3.1	2.4	2.4	0.5	0.5	0.4	2.0	2.5	0.4	2.9	0.2	0.5	1.0	0.5	0.5	0.4	0.3	0.1	0.2	0.1	0.2	0.2	0.1
											+5.7 ft swl													
NE	3.6	2.0	0.8	1.2	0.5	0.1	0.5	0.7	1.2	0.3	0.6	0.1	0.3	0.1	0.1	0.2	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1
	3.9	3.3	3.0	3.4	0.9	0.5	1.6	4.5	3.9	0.4	1.6	0.6	0.5	0.2	0.7	0.2	0.9	1.0	0.2	0.1	0.1	0.1	0.1	0.1
NNE	3.6	2.5	2.0	2.1	0.9	0.4	1.0	3.3	1.5	0.3	0.7	0.3	0.4	0.4	0.2	0.2	0.1	0.6	0.4	0.3	0.1	0.1	0.1	0.1
	4.2	4.8	4.5	3.7	1.1	0.9	1.6	4.6	2.9	1.0	3.8	0.7	0.9	0.7	0.5	0.7	0.7	1.4	0.7	0.6	0.1	0.4	0.4	0.5
N	3.6	2.0	0.4	0.4	0.2	0.2	0.2	0.3	1.0	0.1	0.9	0.1	0.1	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	3.6	3.1	1.5	1.9	0.7	0.3	0.4	2.2	1.7	0.2	1.9	0.1	0.4	0.7	0.2	0.3	0.2	0.2	0.2	0.3	0.1	0.1	0.1	0.1

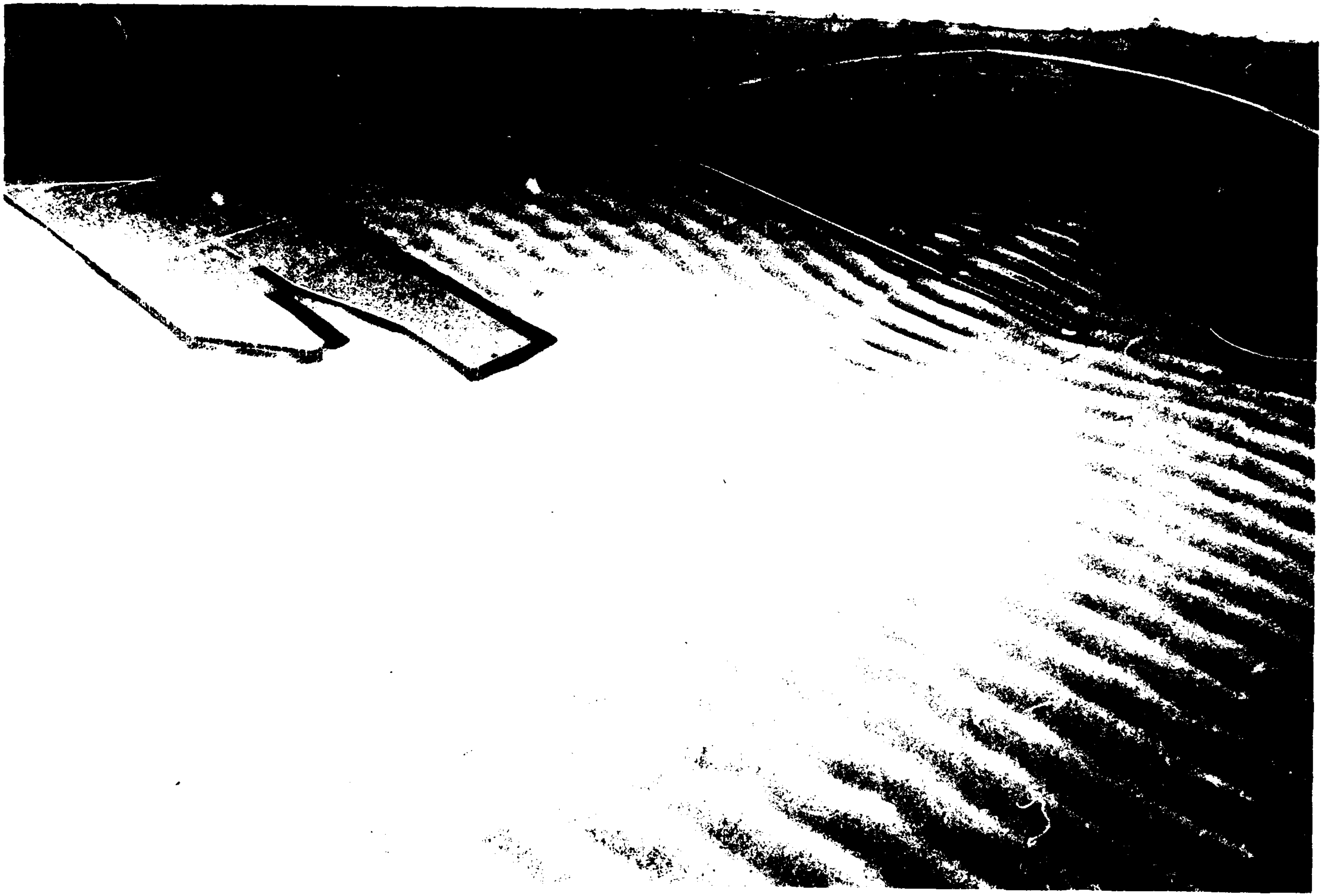

Photo 1. Typical wave patterns for existing conditions; 3.6-sec, 2-ft waves from northeast; +5.7 ft swl

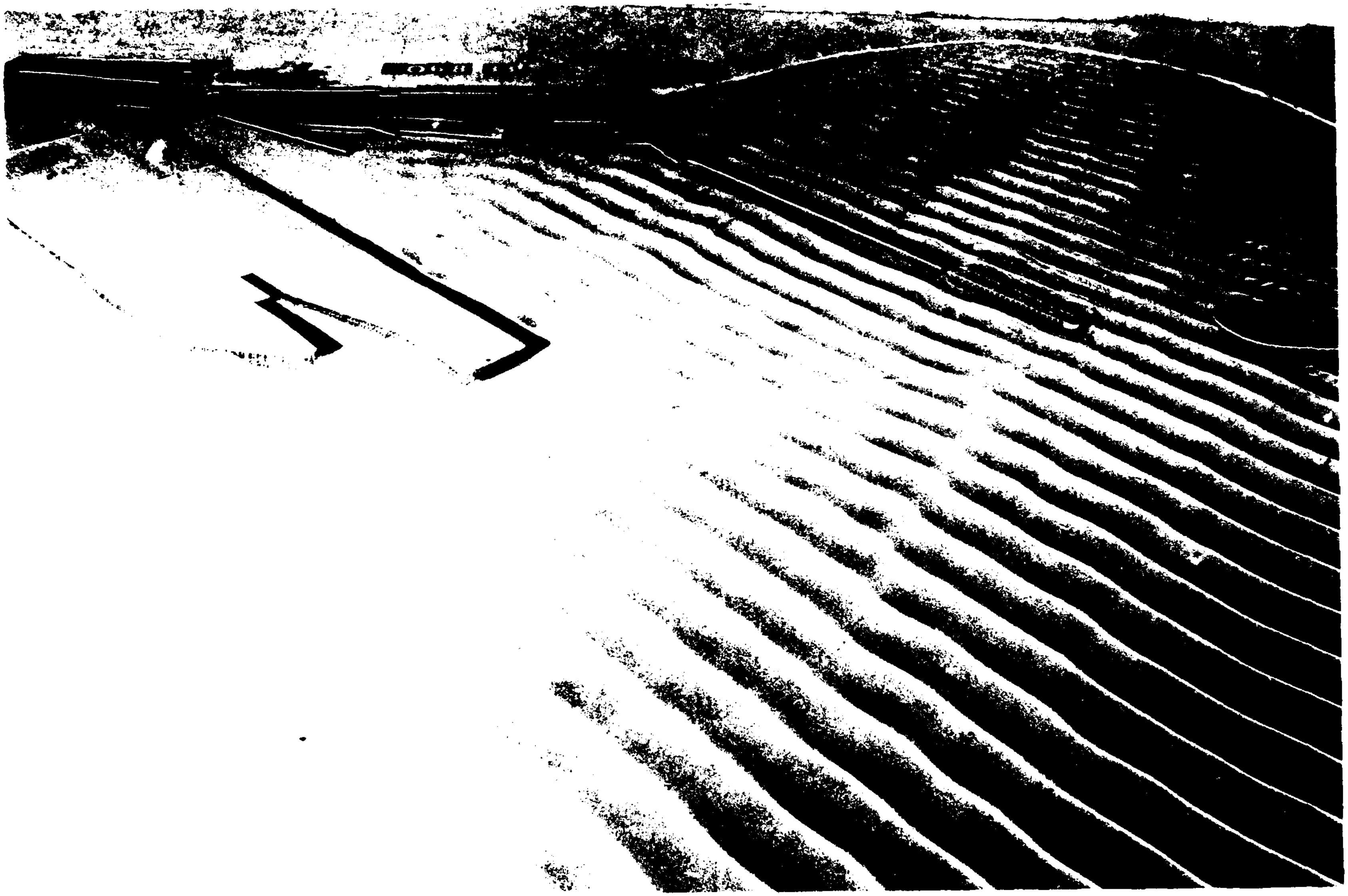

Photo 2. Typical wave patterns for existing conditions; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

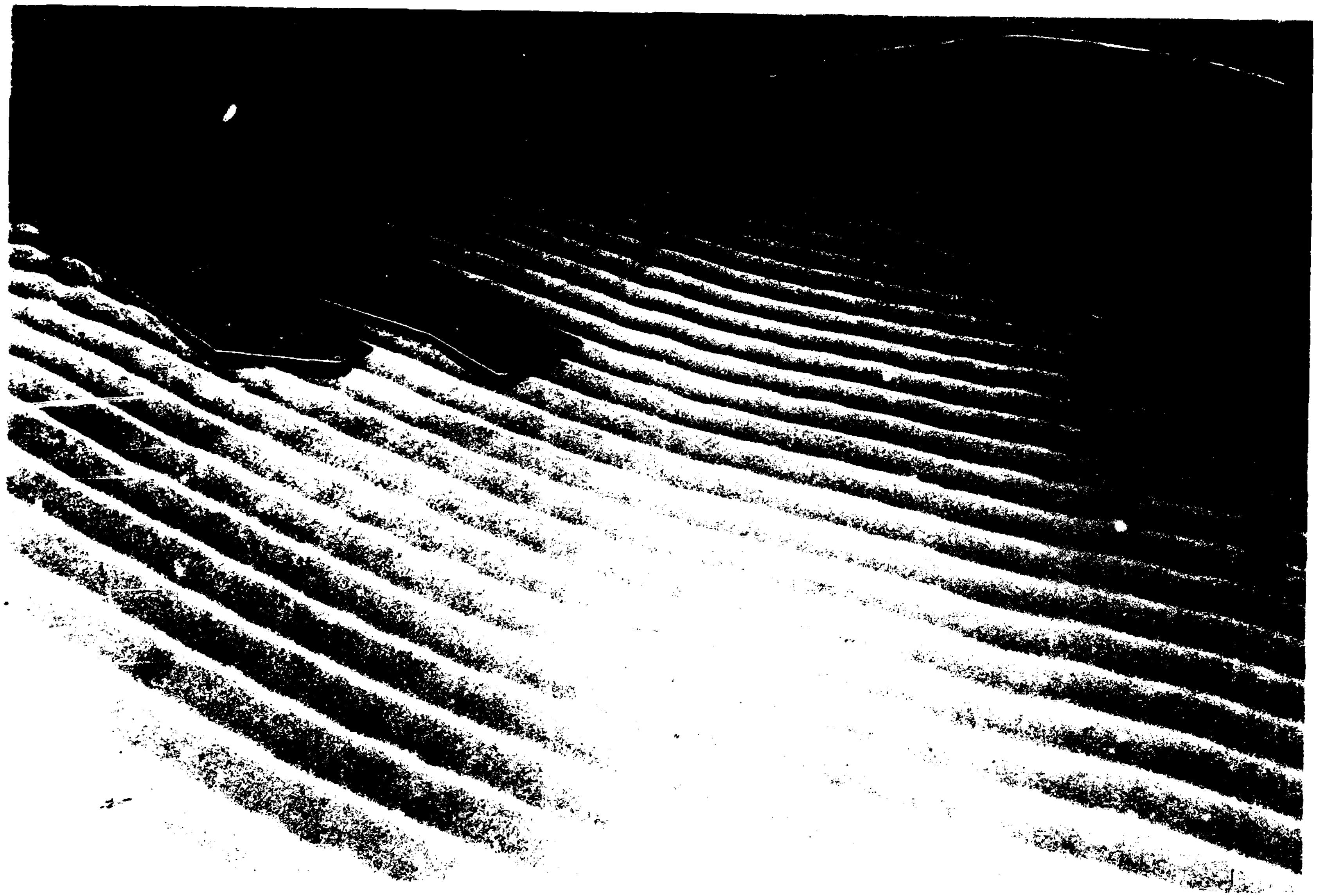

Photo 3. Typical wave patterns for existing conditions; 3.6-sec, 2.5-ft waves from north-northeast; +5.7 ft swl

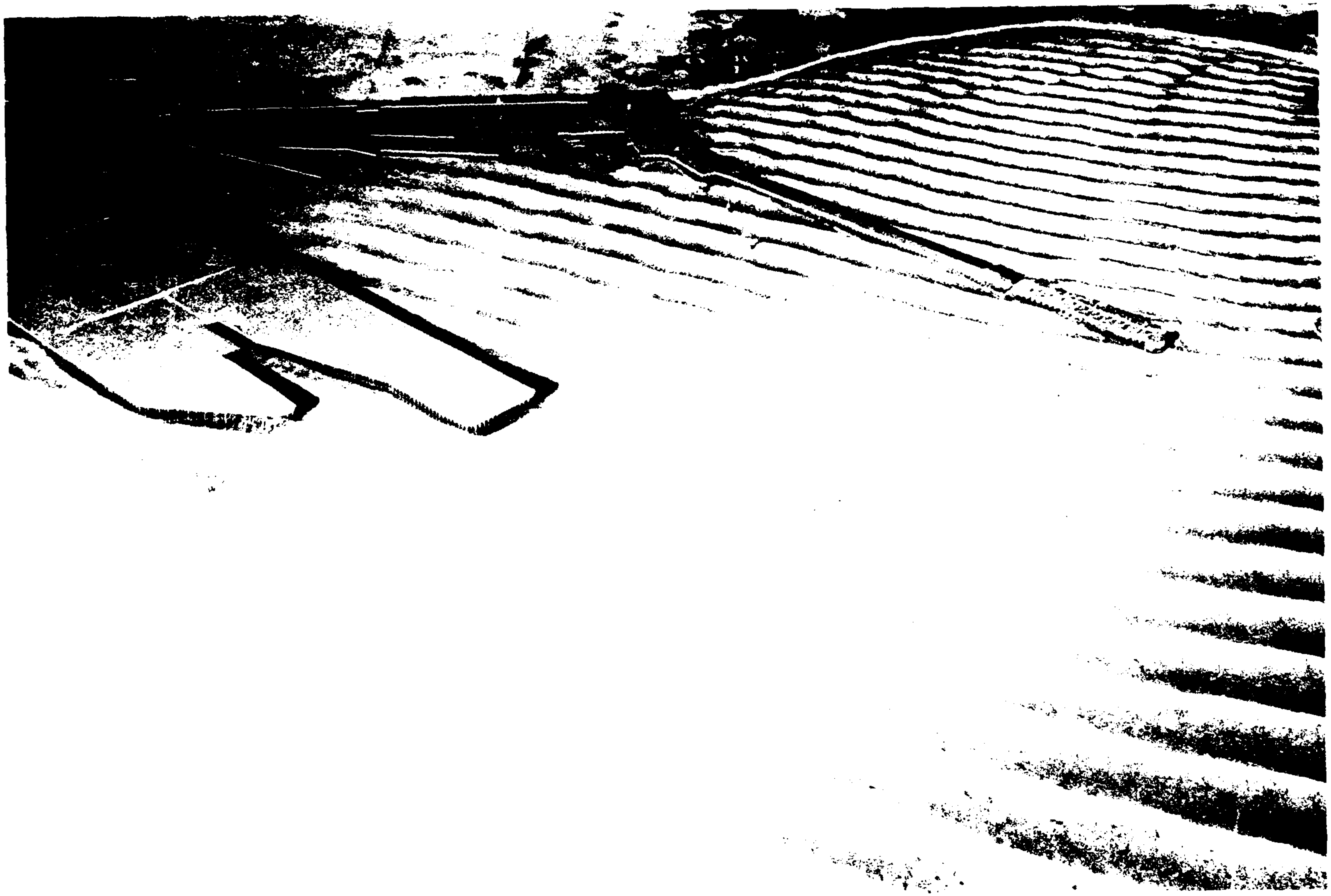

Photo 4. Typical wave patterns for existing conditions; 4.2-sec, 4.8-ft waves from north-northeast; +5.7 ft swl

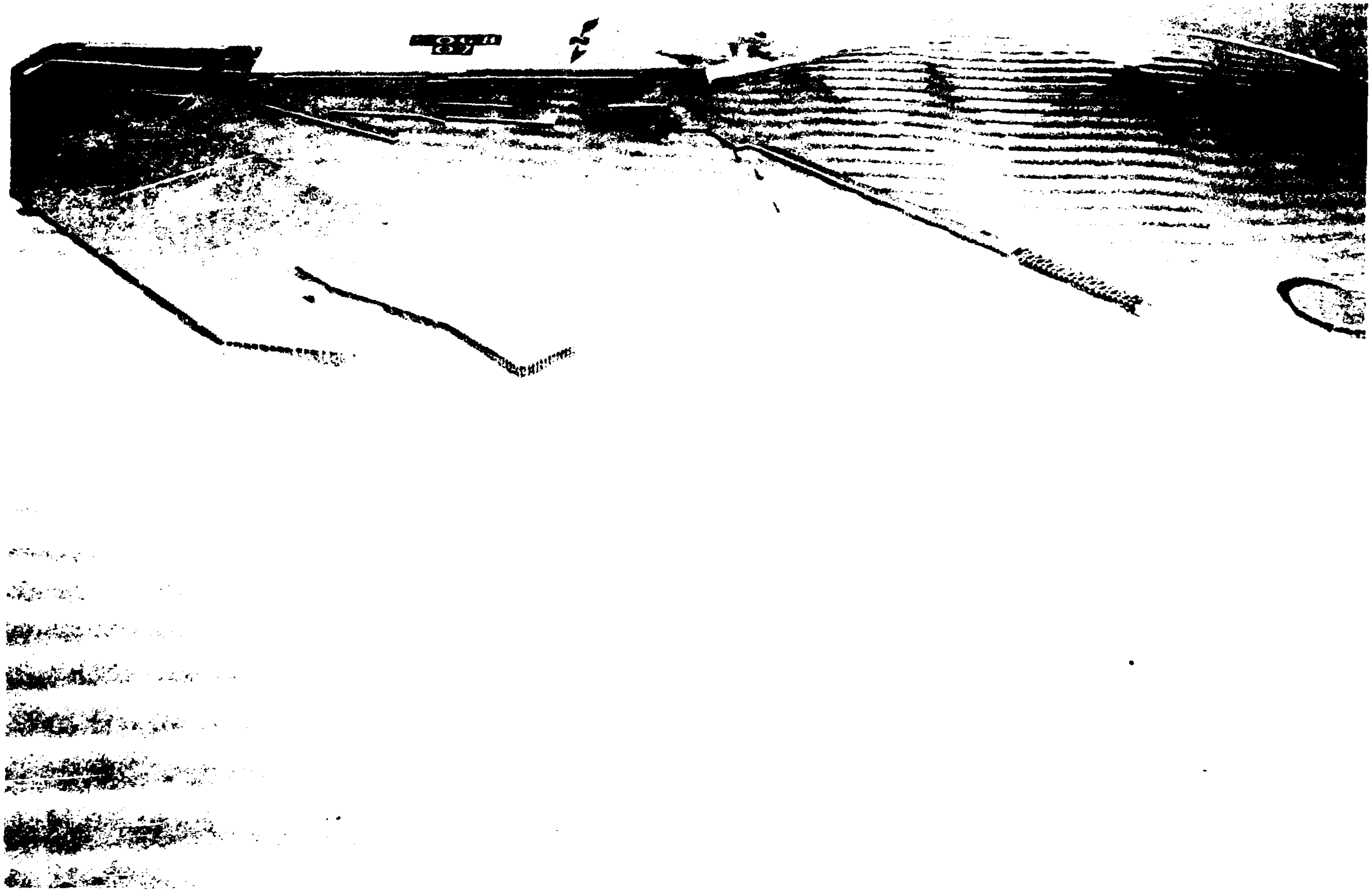

Photo 5. Typical wave patterns for existing conditions; 3.6-sec, 2-ft waves from north; +5.7 ft swl

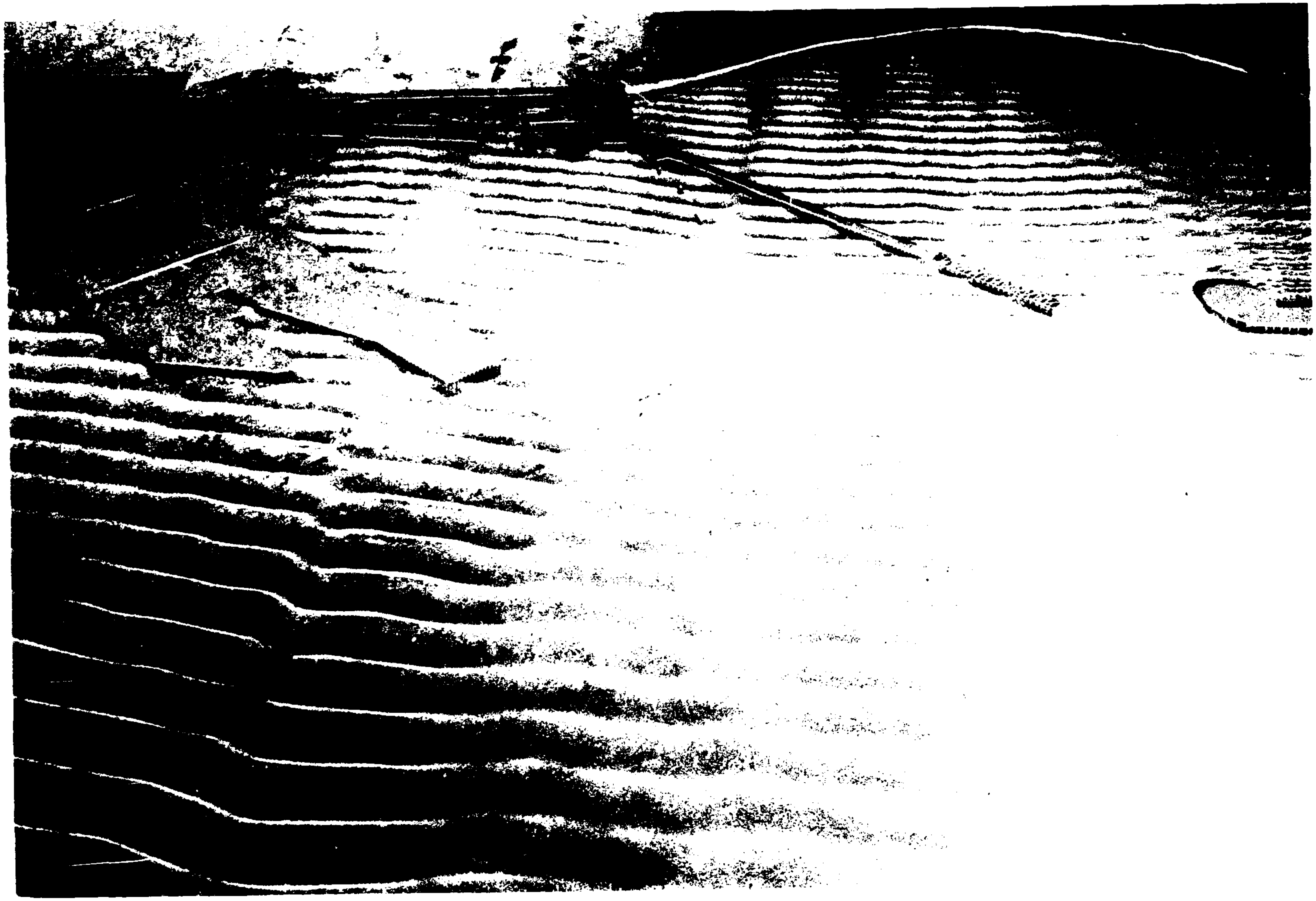

Photo 6. Typical wave patterns for existing conditions; 3.6-sec, 3.1-ft waves from north; +5.7 ft swl

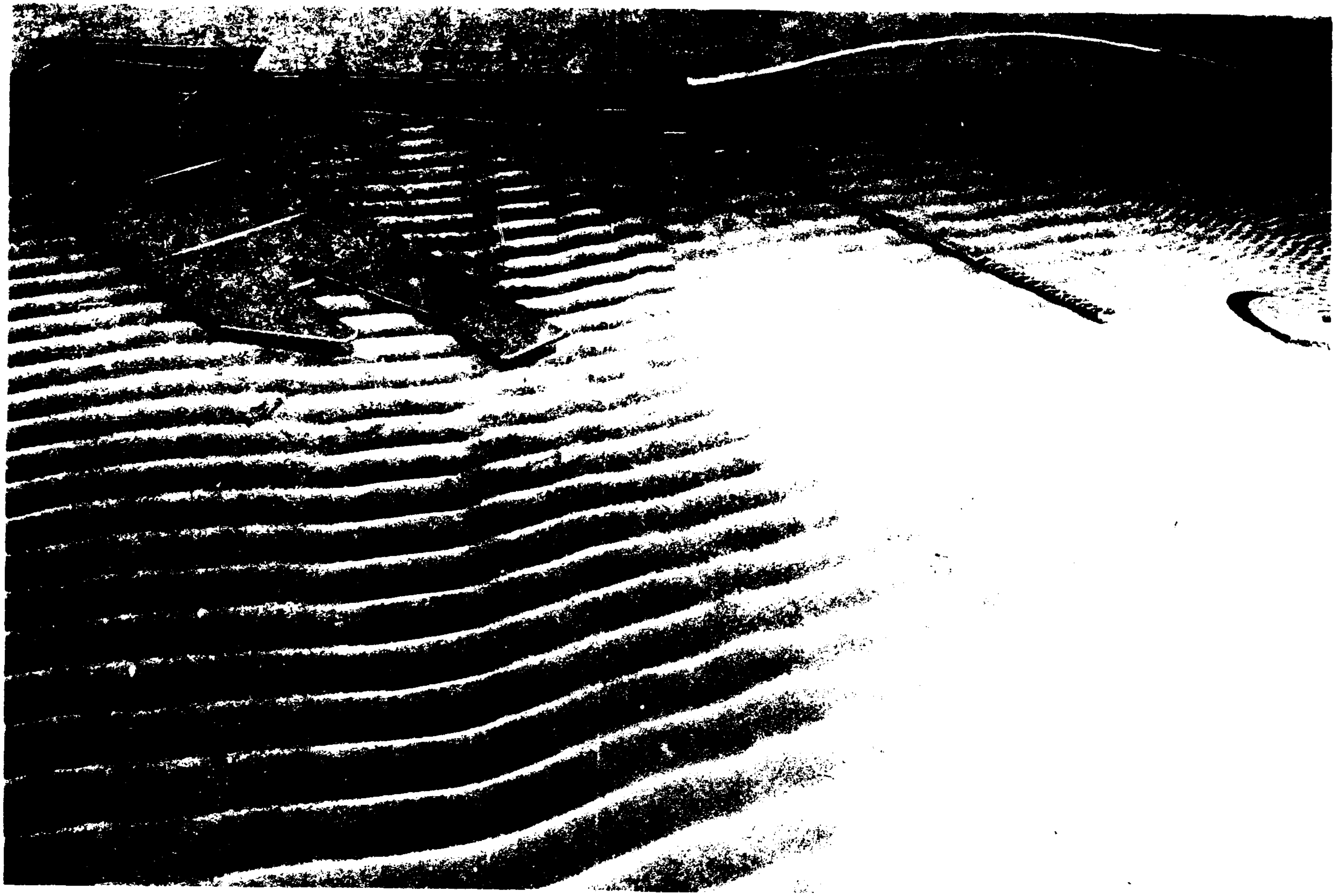

Photo 7. Typical wave patterns for existing conditions; 3.6-sec, 2-ft waves from north-northwest; +5.7 ft swl

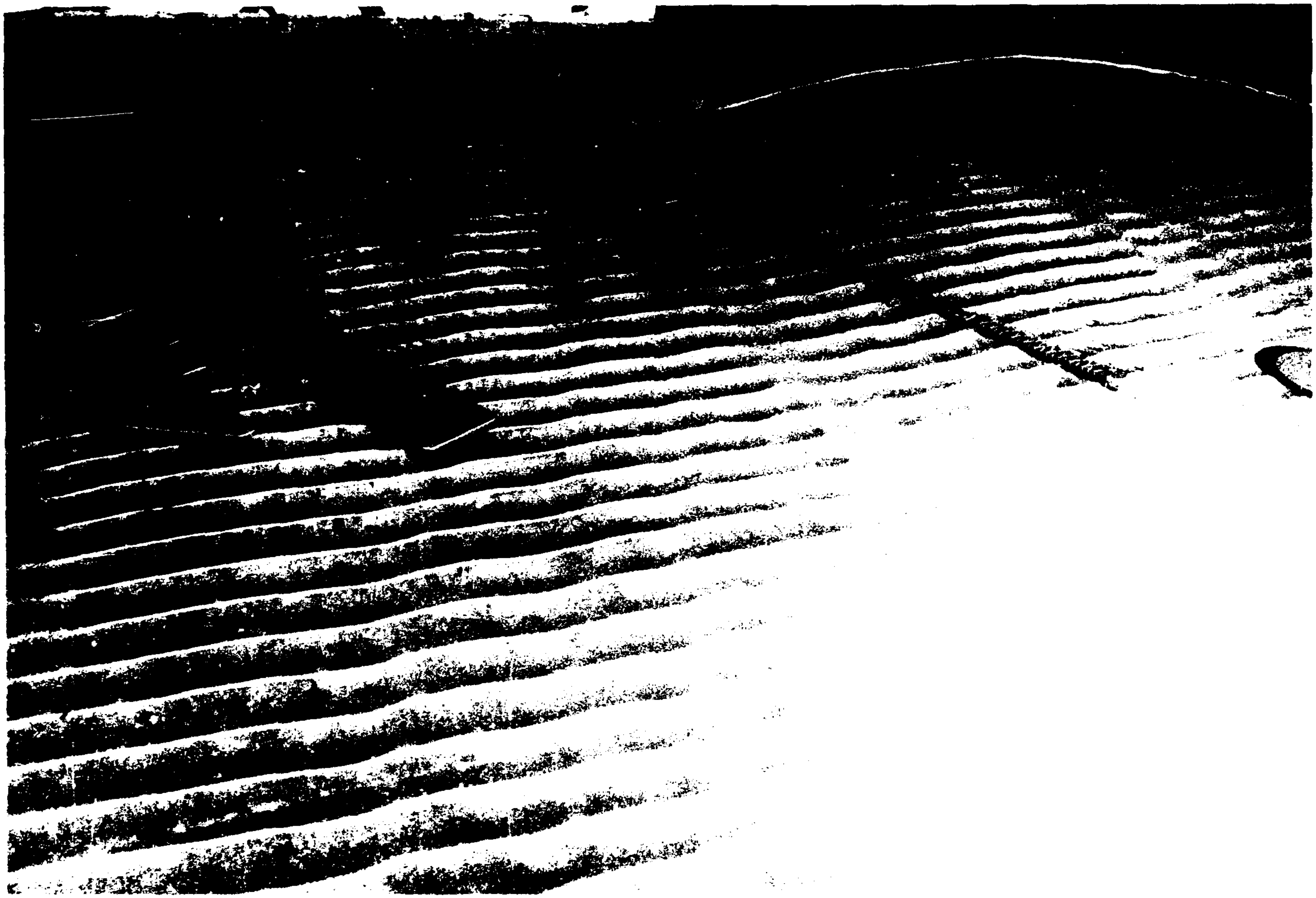

Photo 8. Typical wave patterns for existing conditions; 3.6-sec, 3.3-ft waves from north-northwest; +5.7 ft swl

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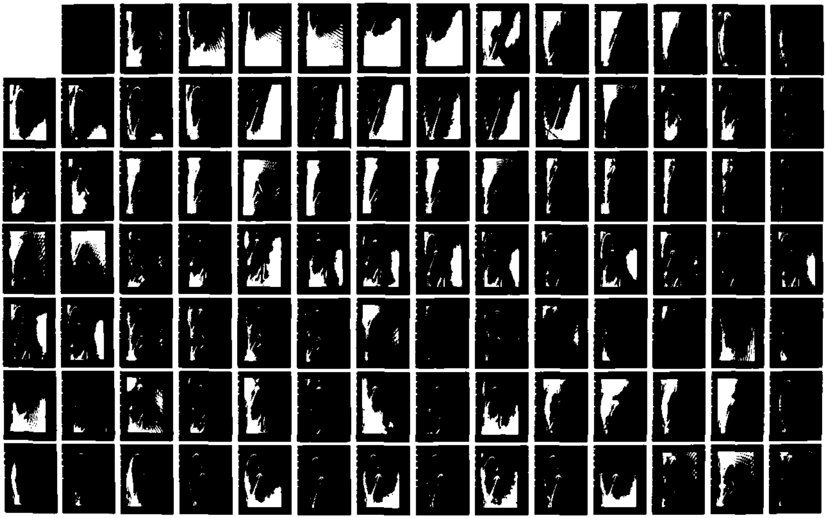

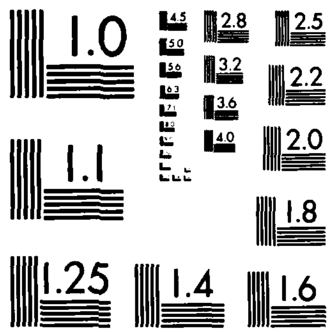

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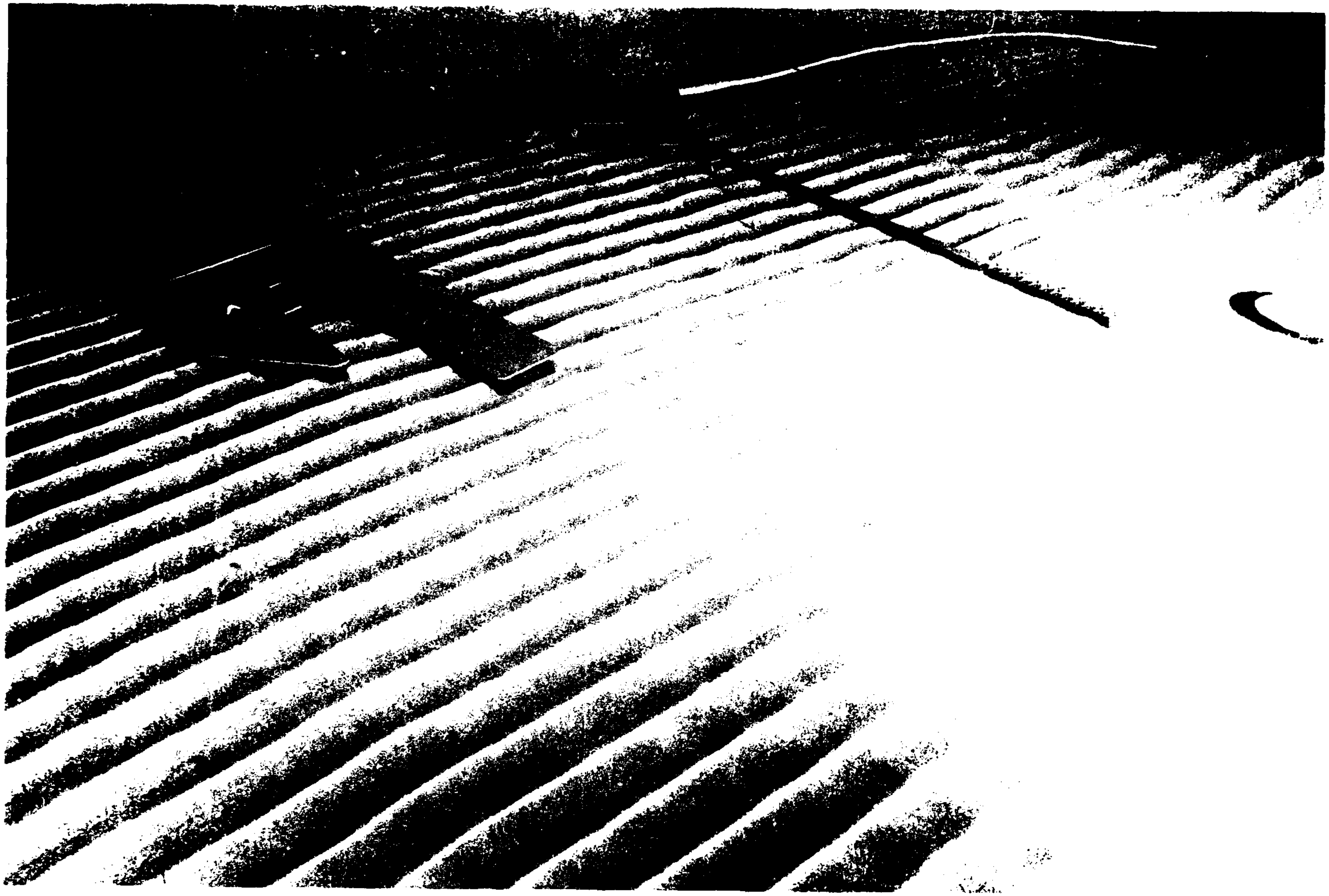

Photo 9. Typical wave patterns for existing conditions; 3.6-sec, 2-ft waves from northwest; +5.7 ft swl

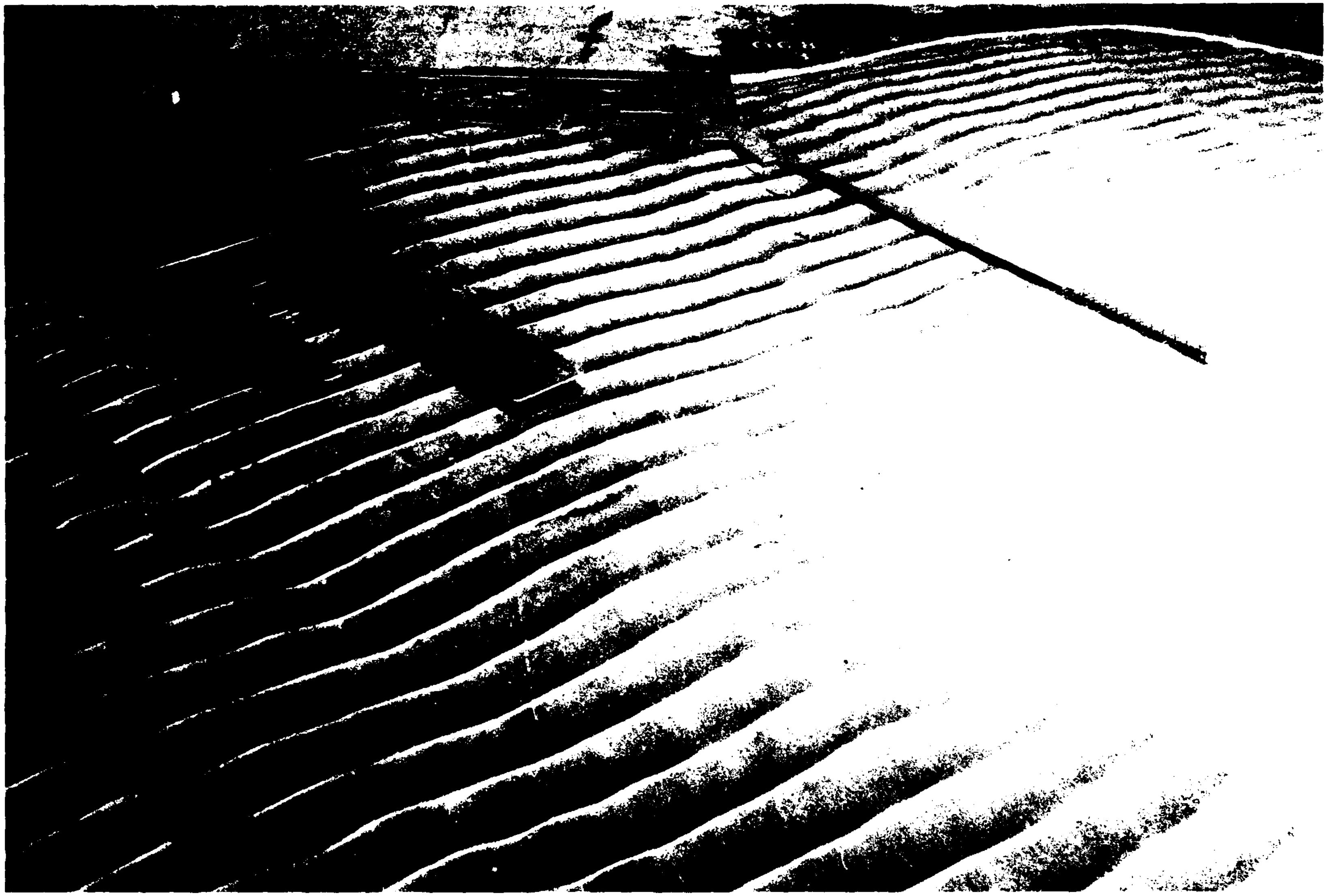

Photo 10. Typical wave patterns for existing conditions; 3.8-sec, 4.1-ft waves from northwest; +5.7 ft swl

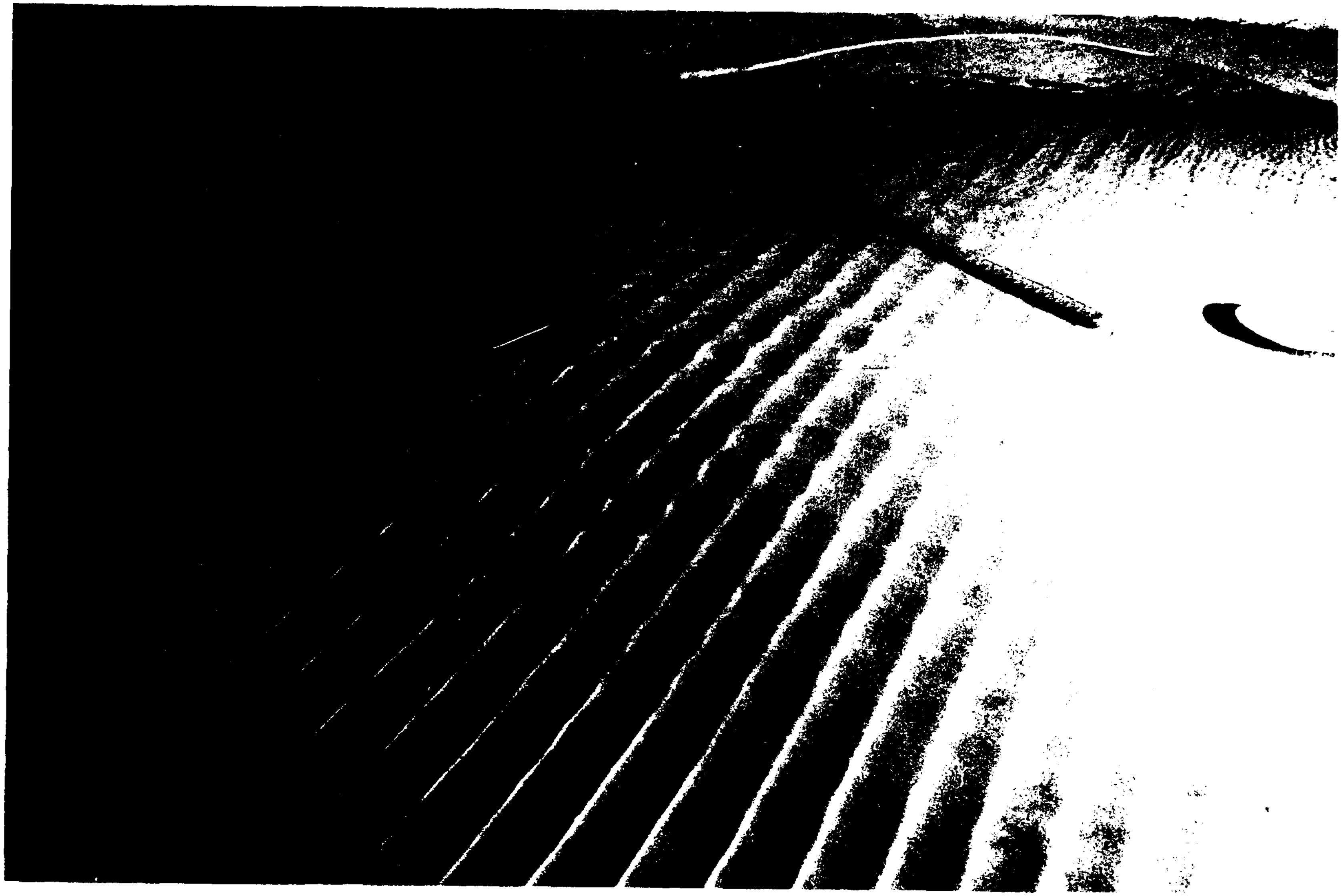

Photo 11. Typical wave patterns for existing conditions; 3.6-sec, 2-ft waves from west-northwest; +5.7 ft swl

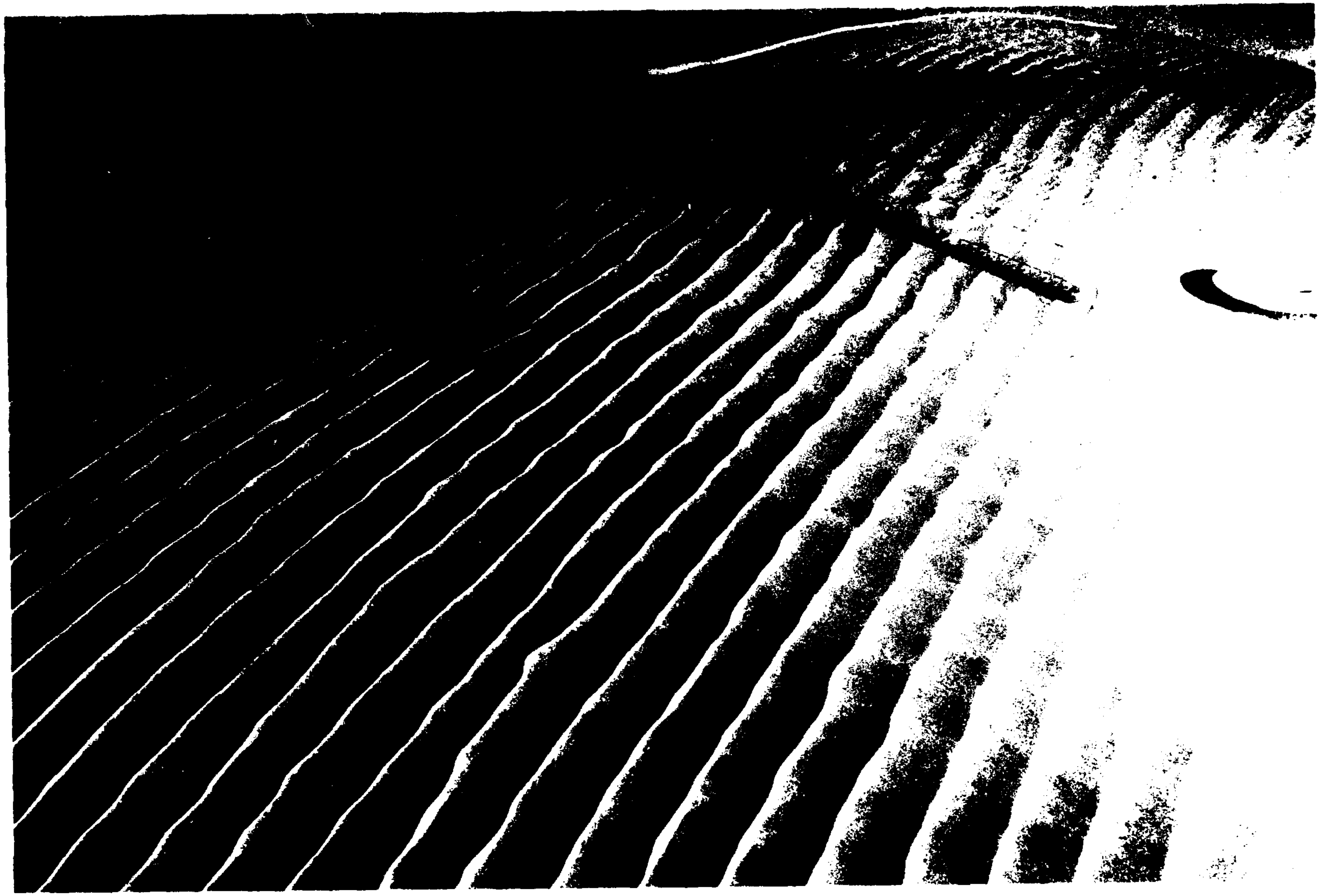

Photo 12. Typical wave patterns for existing conditions; 3.6-sec, 3.4-ft waves from west-northwest; +5.7 ft swl

Photo 13. Typical wave patterns for existing conditions; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

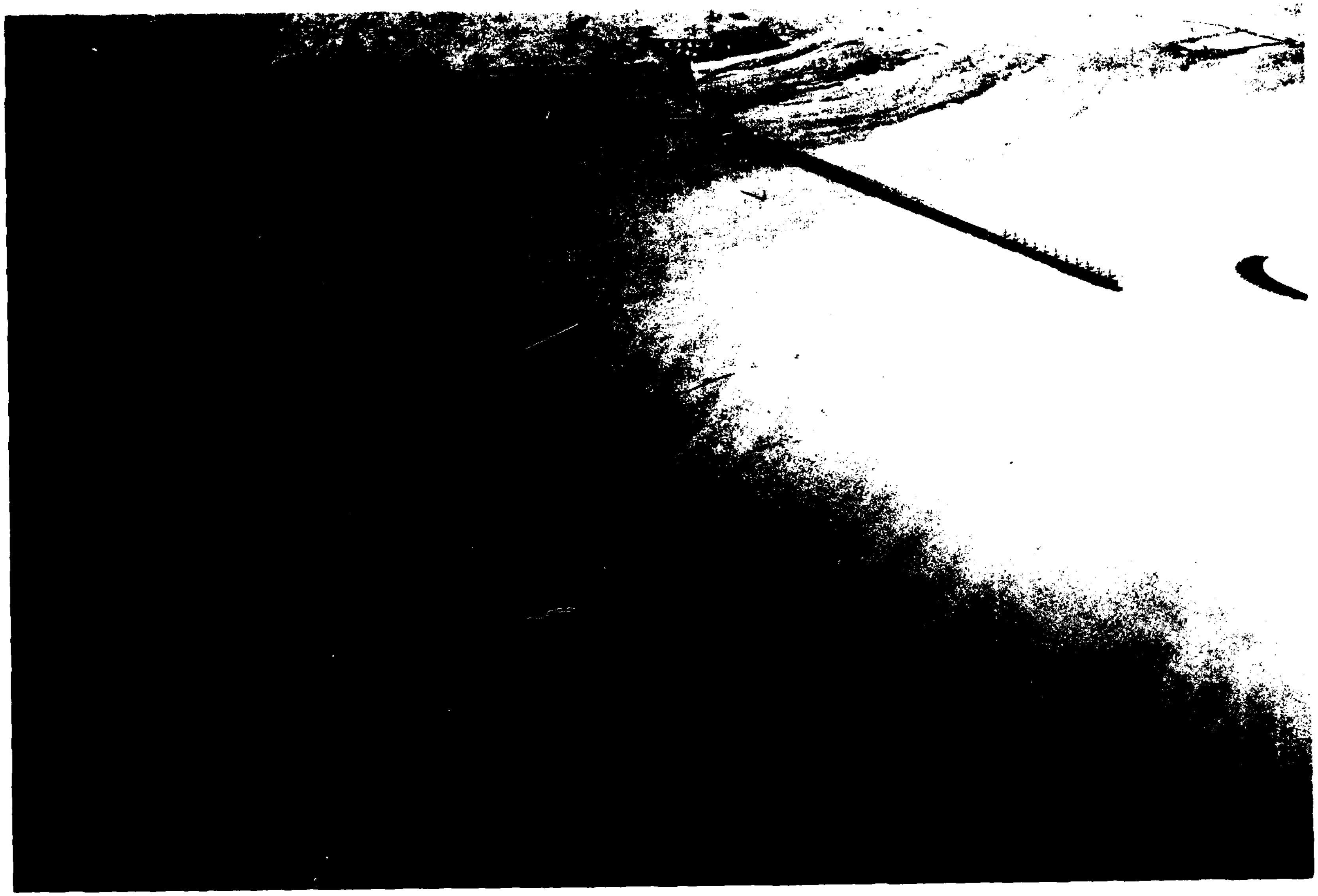

Photo 14. Typical wave patterns for existing conditions; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

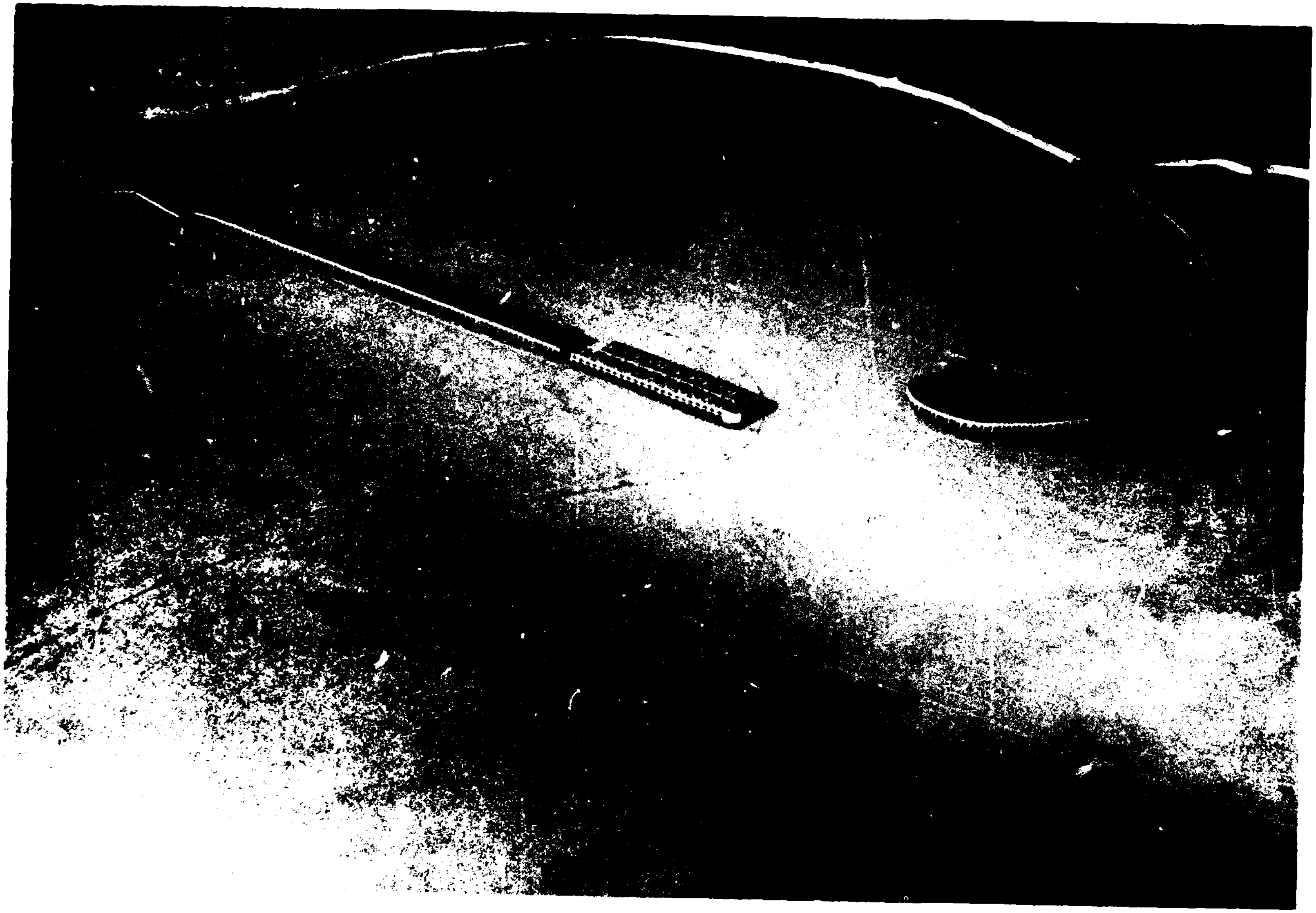

Photo 15. General movement of tracer material for existing conditions; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

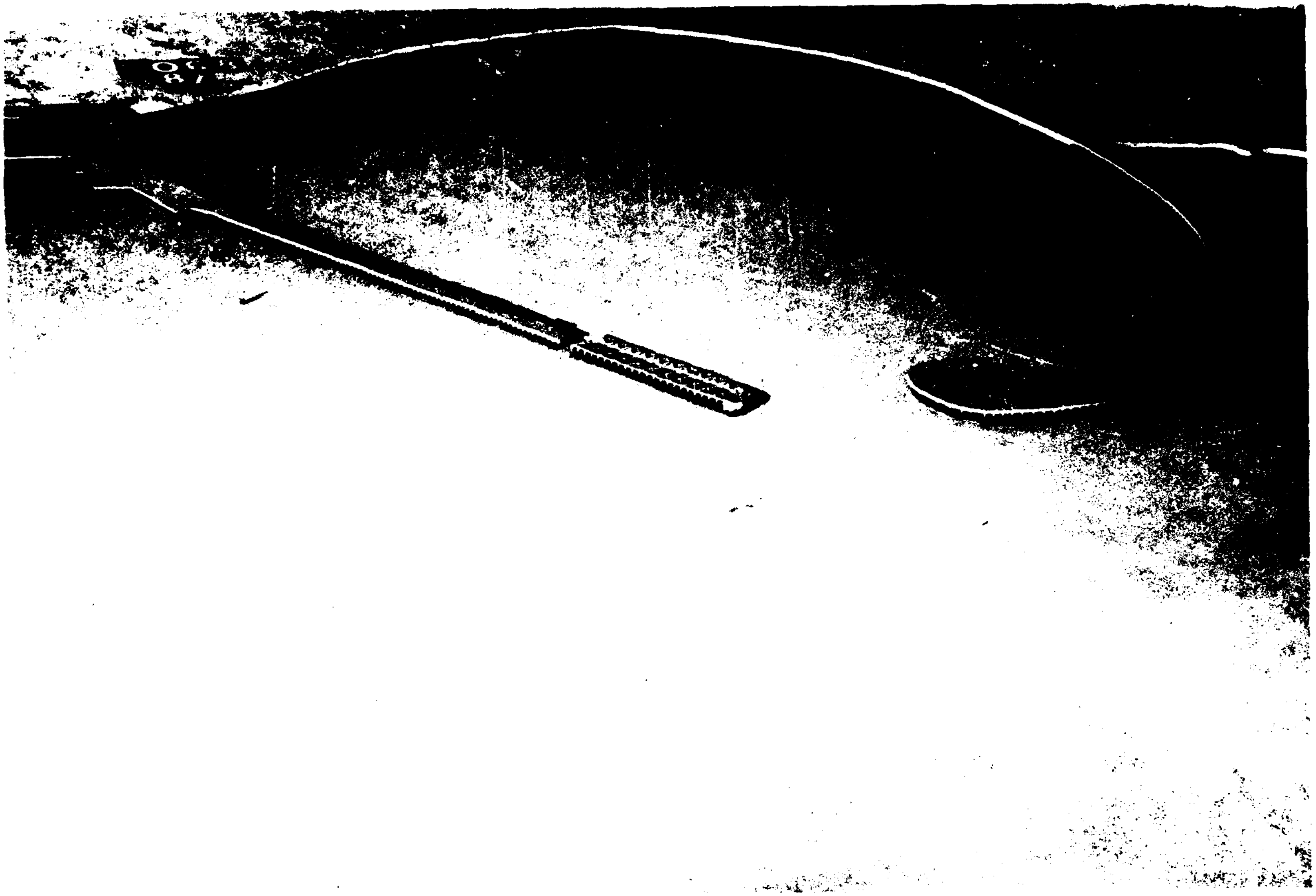

Photo 16. General movement of tracer material for existing conditions; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

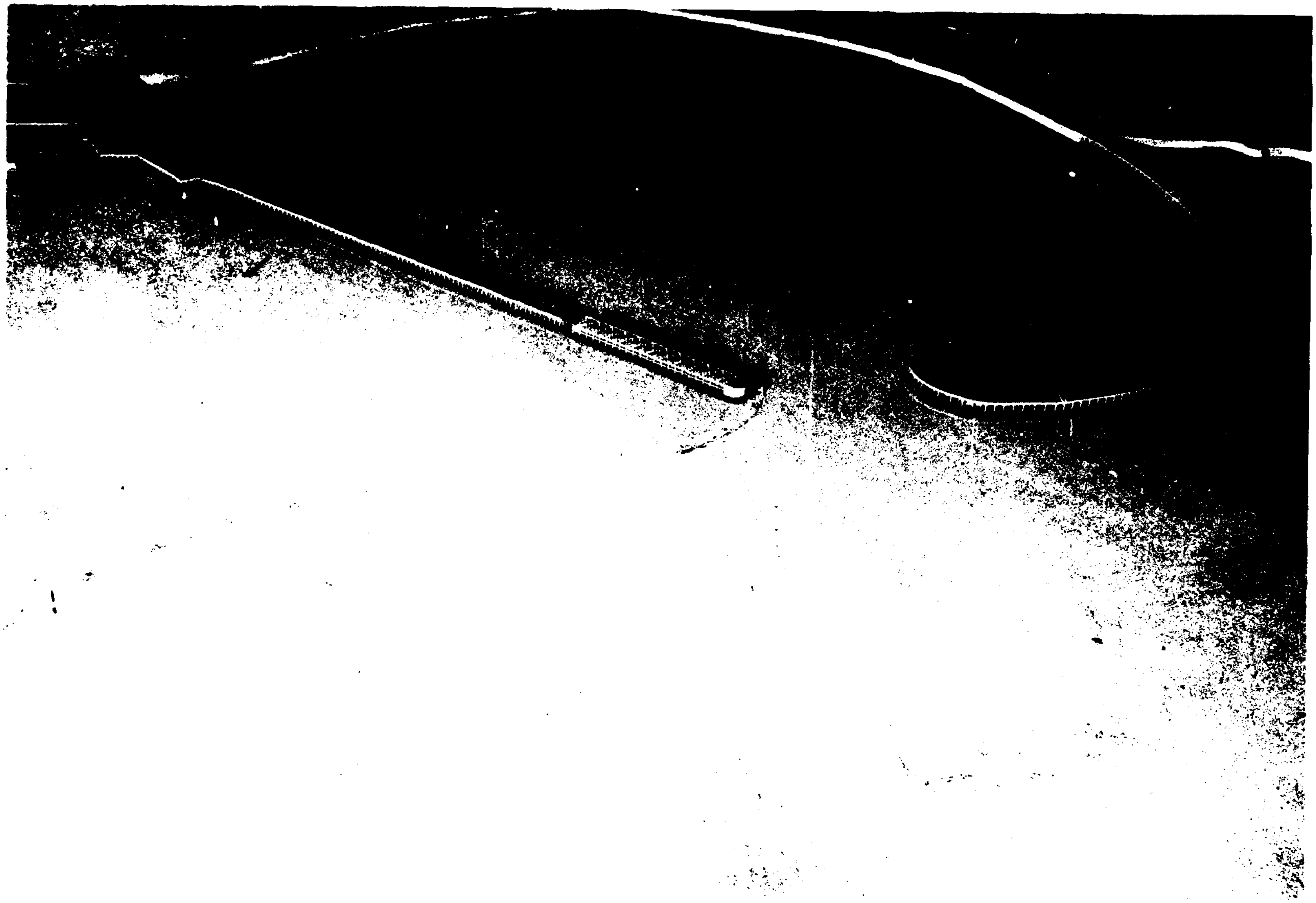

Photo 17. General movement of tracer material for existing conditions; 4.2-sec, 4.8-ft waves from north-northeast; 0.0-ft swl

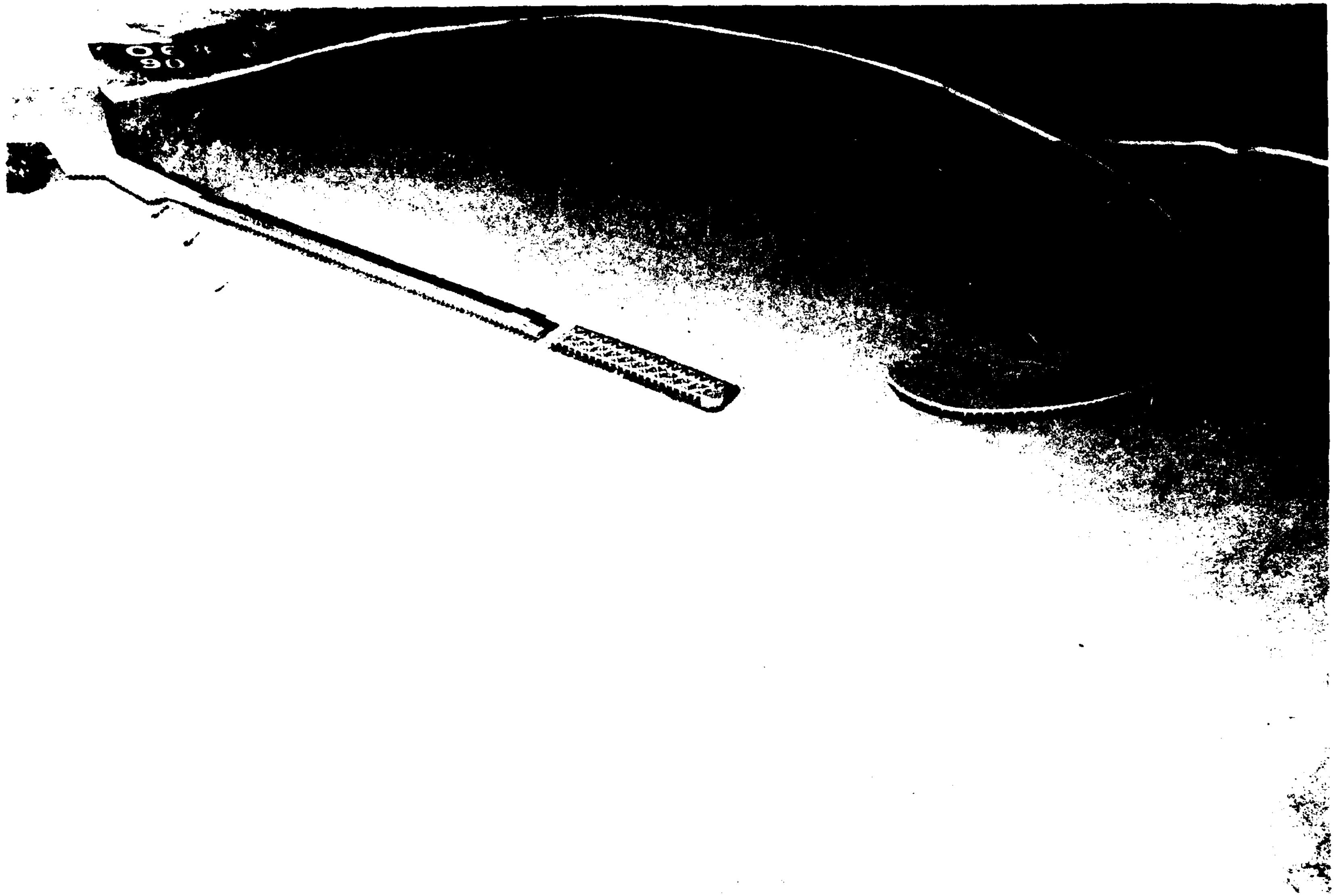

Photo 18. General movement of tracer material for existing conditions; 4.2-sec, 4.8-ft waves from north-northeast; +5.7 ft swl

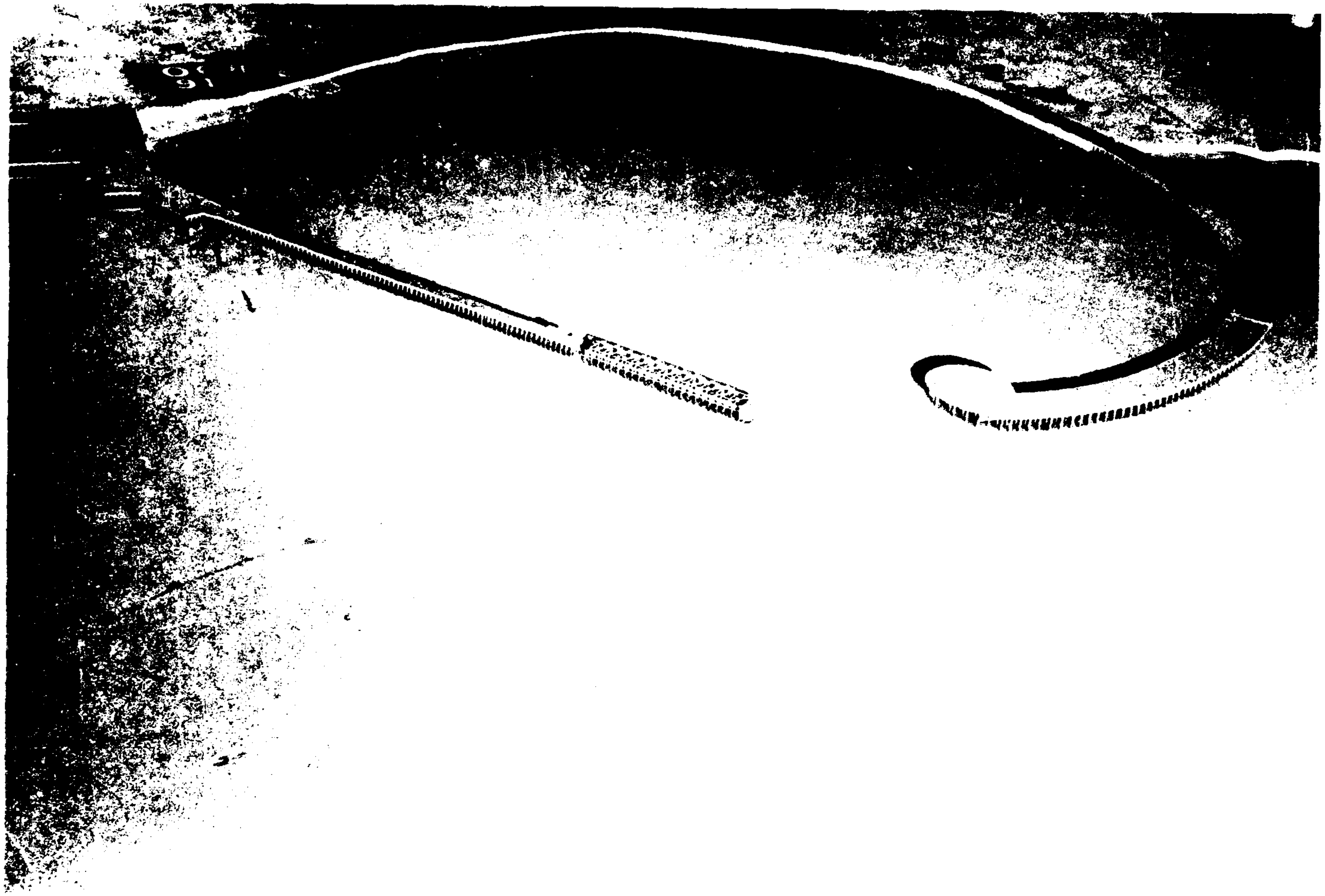

Photo 19. General movement of tracer material for existing conditions; 3.6-sec, 3.1-ft waves from north; 0.0-ft swl

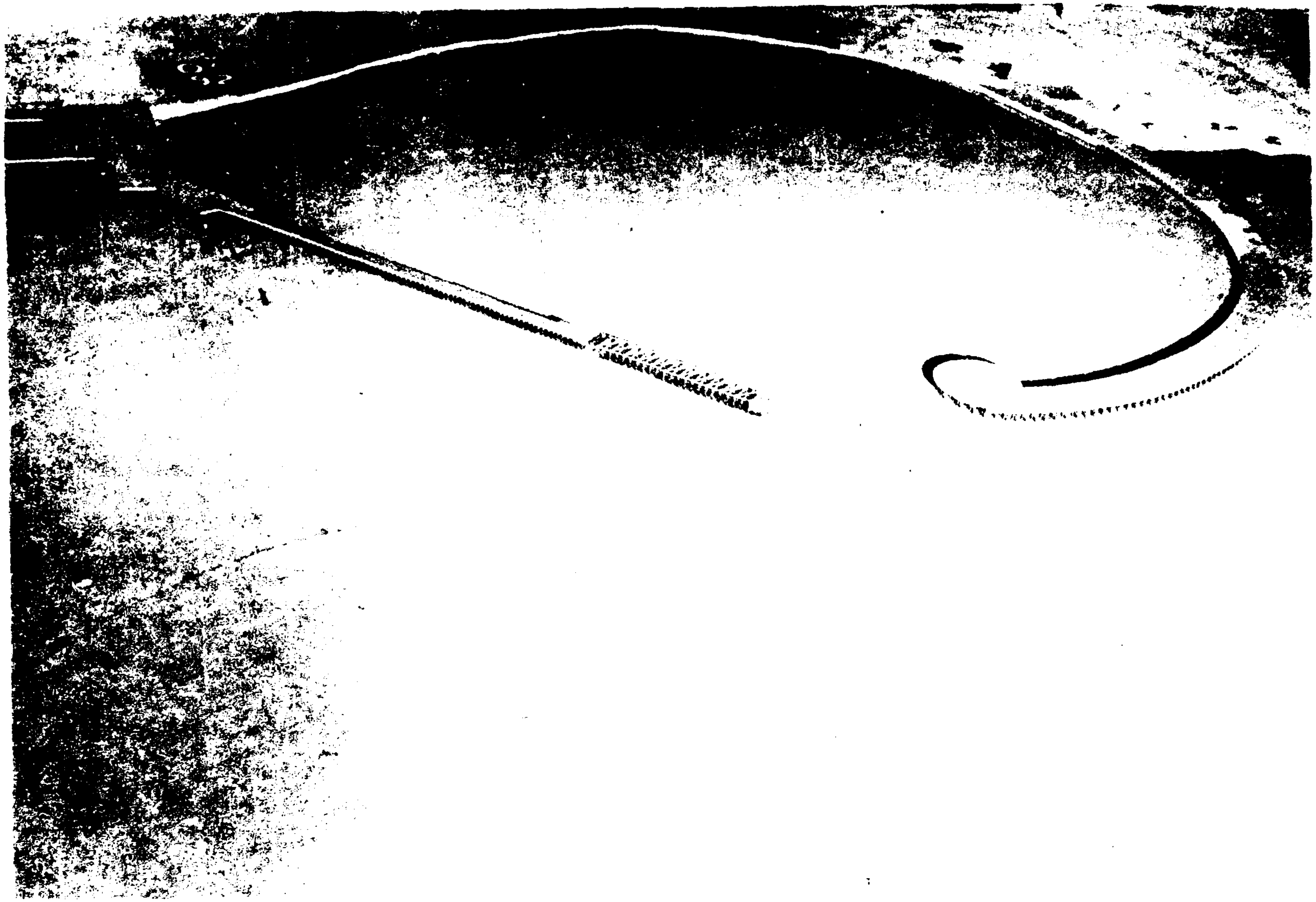

Photo 20. General movement of tracer material for existing conditions; 3.6-sec, 3.1-ft waves from north; +5.7 ft swl

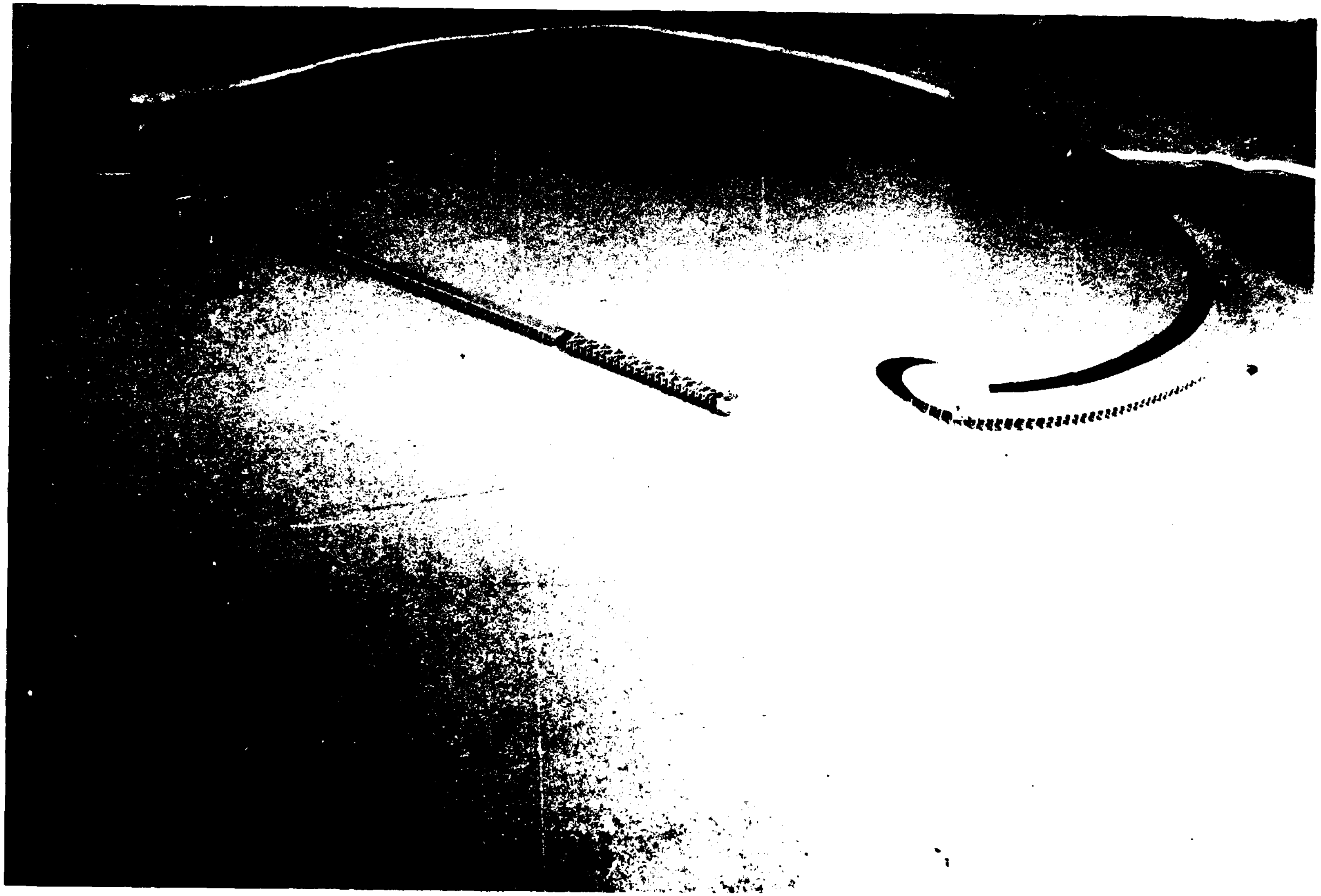

Photo 21. General movement of tracer material for existing conditions; 3.6-sec, 3.3-ft waves from north-northwest; 0.0-ft swl

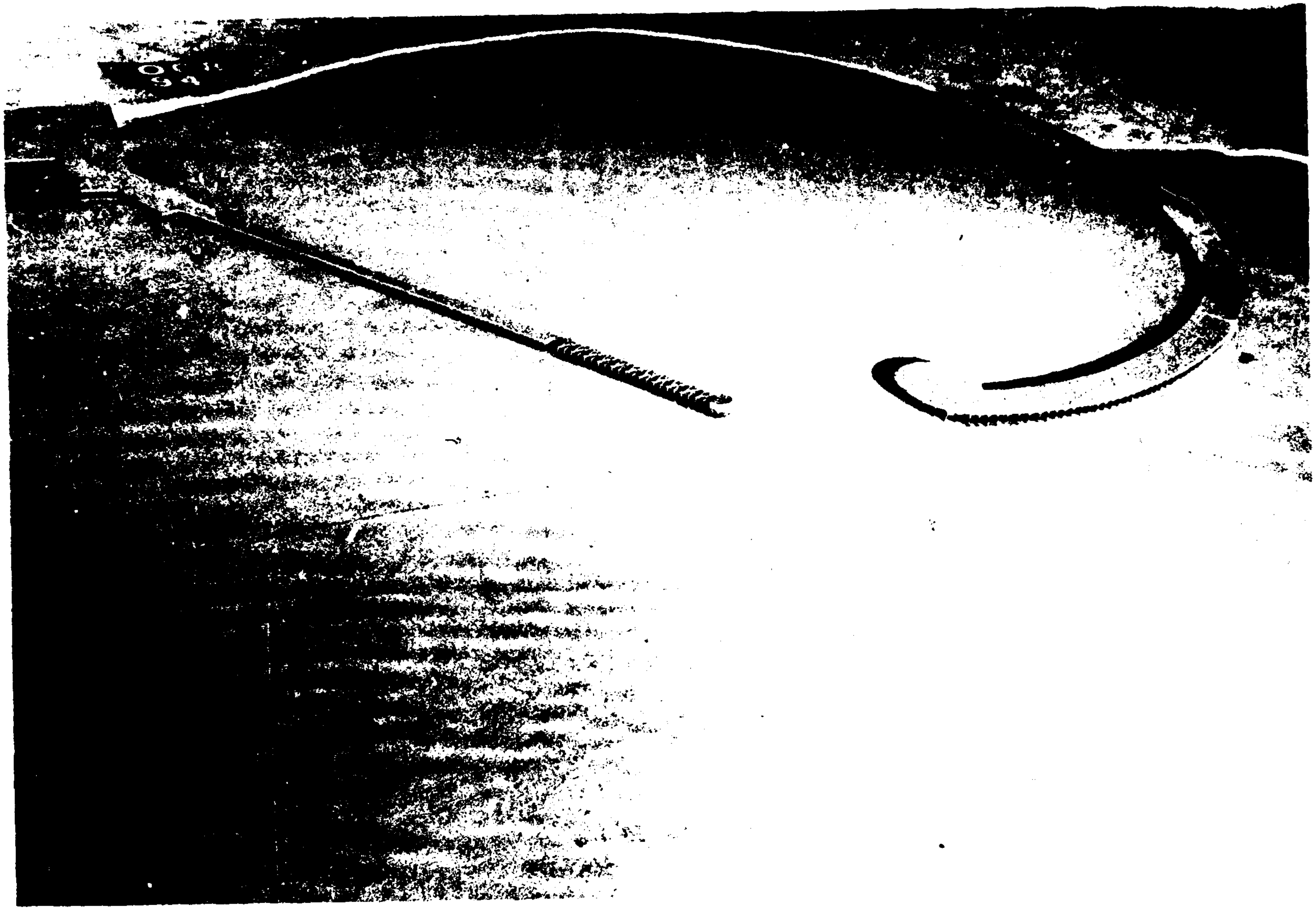

Photo 22. General movement of tracer material for existing conditions; 3.6-sec, 3.3-ft waves from north-northwest; +5.7 ft swl

Photo 23. General movement of tracer material for existing conditions; 3.8-sec, 4.1-ft waves from northwest; 0.0-ft swl

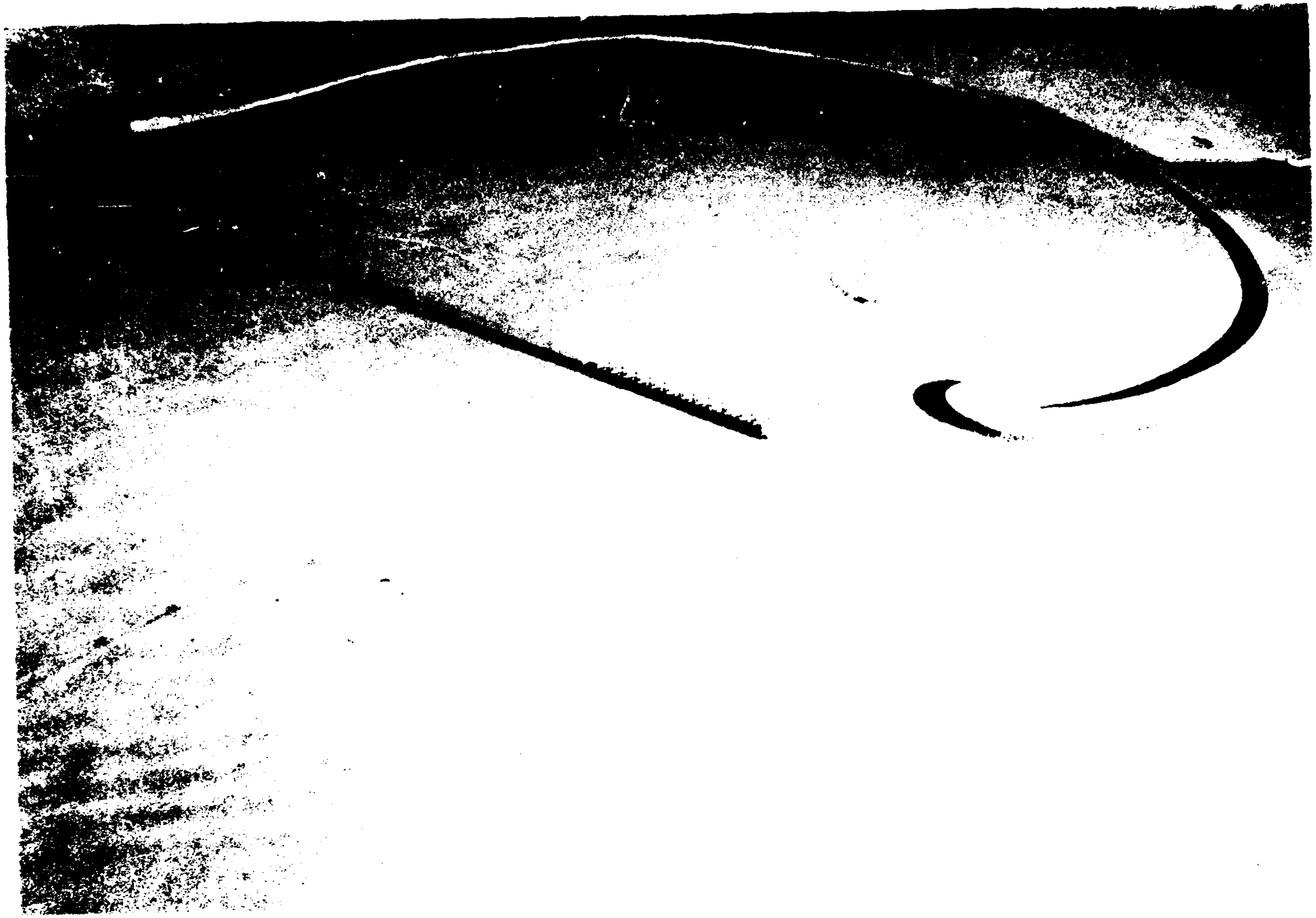

Photo 24. General movement of tracer material for existing conditions; 3.8-sec, 4.1-ft waves from northwest; +5.7 ft swl

Photo 25. General movement of tracer material for existing conditions; 3.6-sec, 3.4-ft waves from west-northwest; 0.0-ft swl

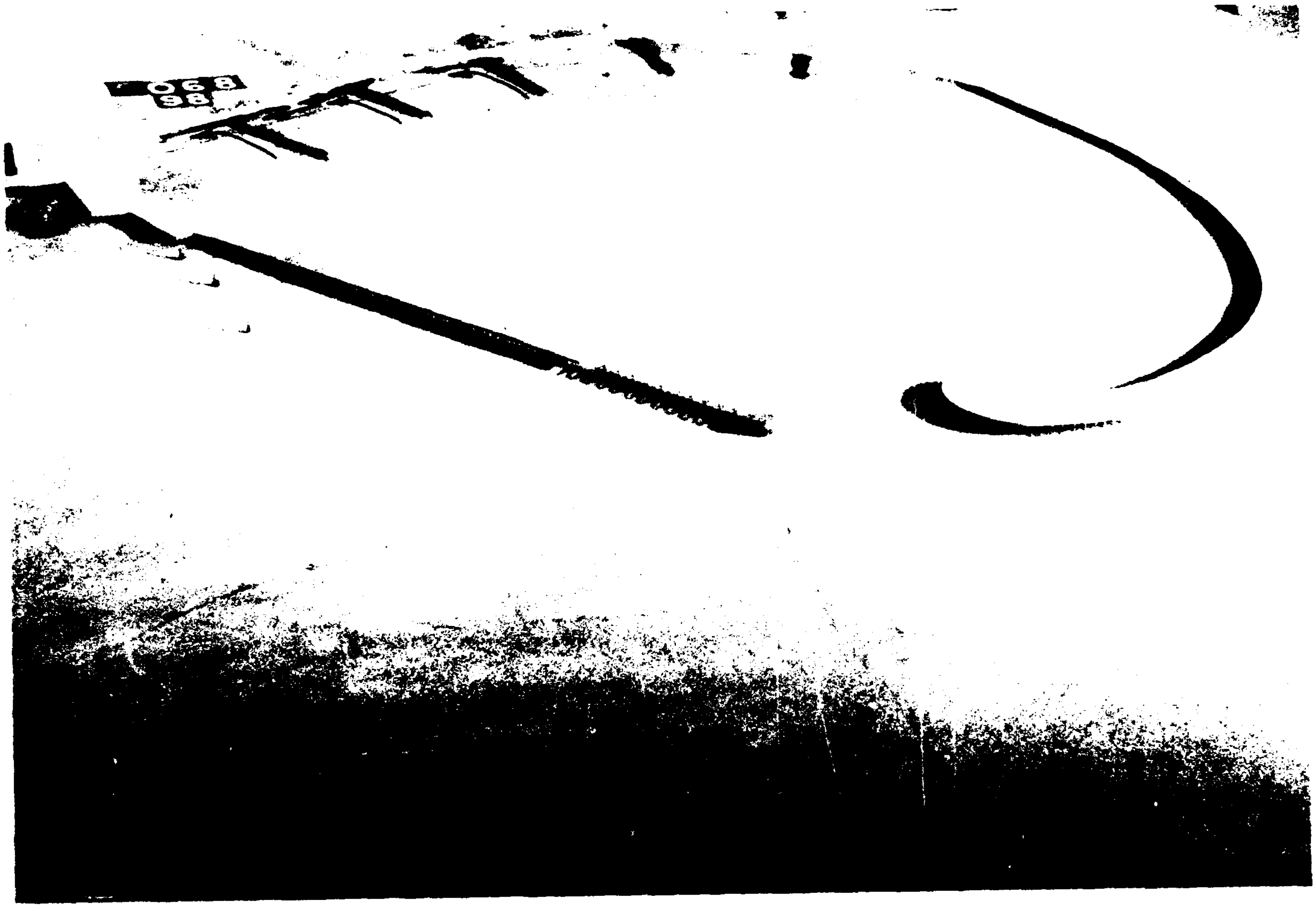

Photo 26. General movement of tracer material for existing conditions; 3.6-sec, 3.4-ft waves from west-northwest; +5.7 ft swl

Photo 27. General movement of tracer material for existing conditions; 10-sec, 2-ft waves from west-northwest; 0.0-ft swl

Photo 28. General movement of tracer material for existing conditions; 10-sec, 2-ft waves from weat-northwest; +5.7 ft swl

Photo 29. General movement of tracer material for existing conditions; 10-sec, 3-ft waves from weat-northwest; 0.0-ft swl

Photo 30. General movement of tracer material for existing conditions; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

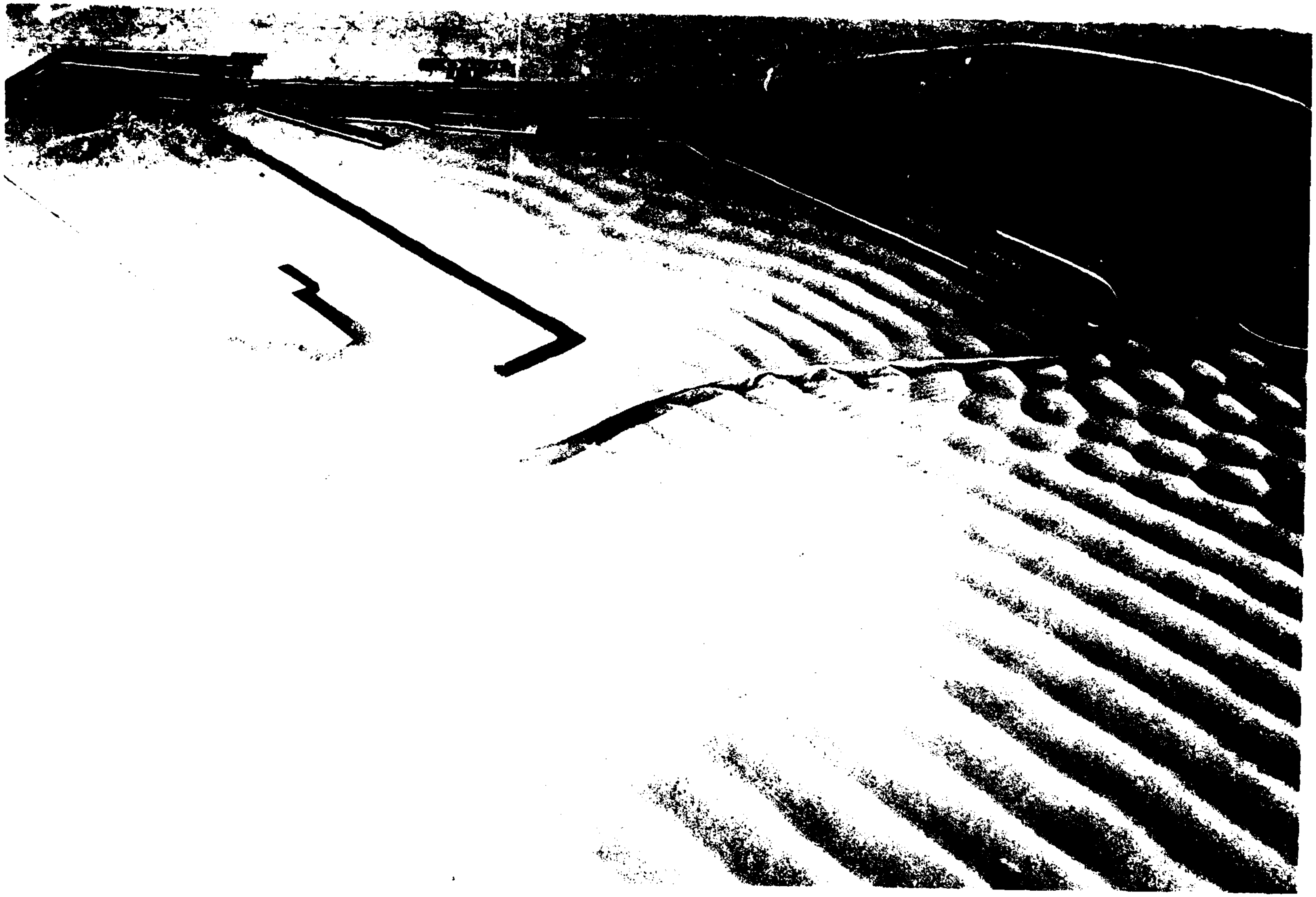

Photo 31. Typical wave patterns for Plan 1; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

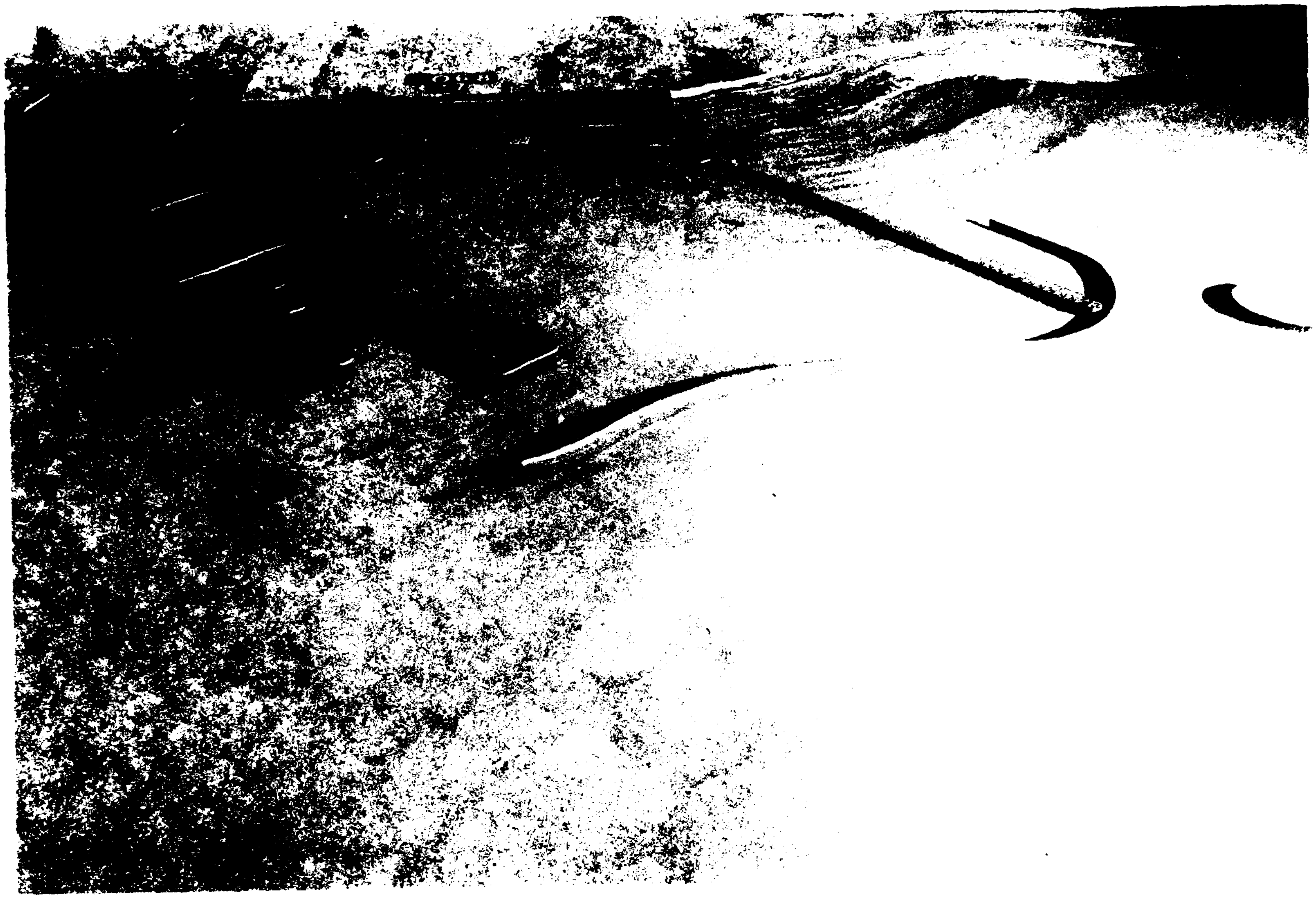

Photo 32. Typical wave patterns for Plan 1; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

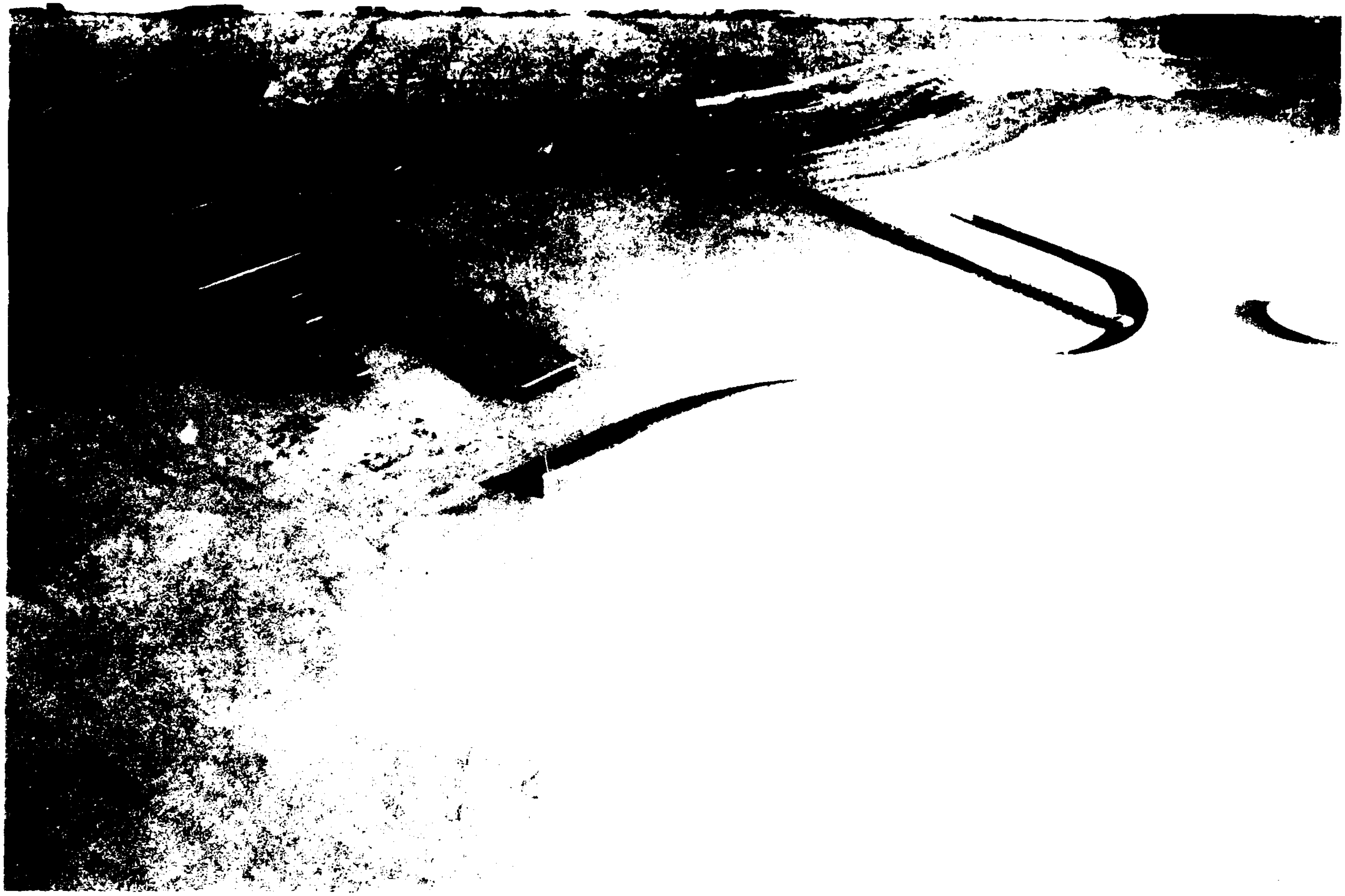

Photo 33. Typical wave patterns for Plan 2; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

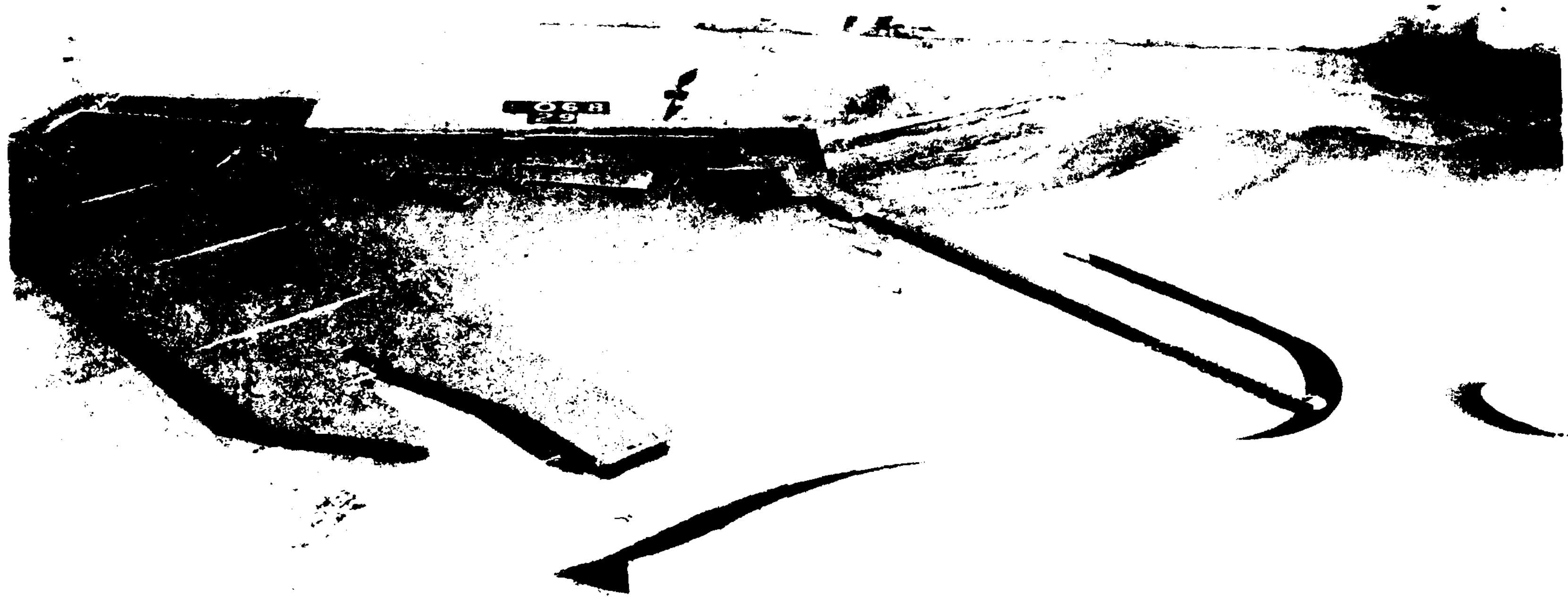

Photo 34. Typical wave patterns for Plan 3; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

Photo 35. Typical wave patterns for Plan 4; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

Photo 36. Typical wave patterns for Plan 5; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

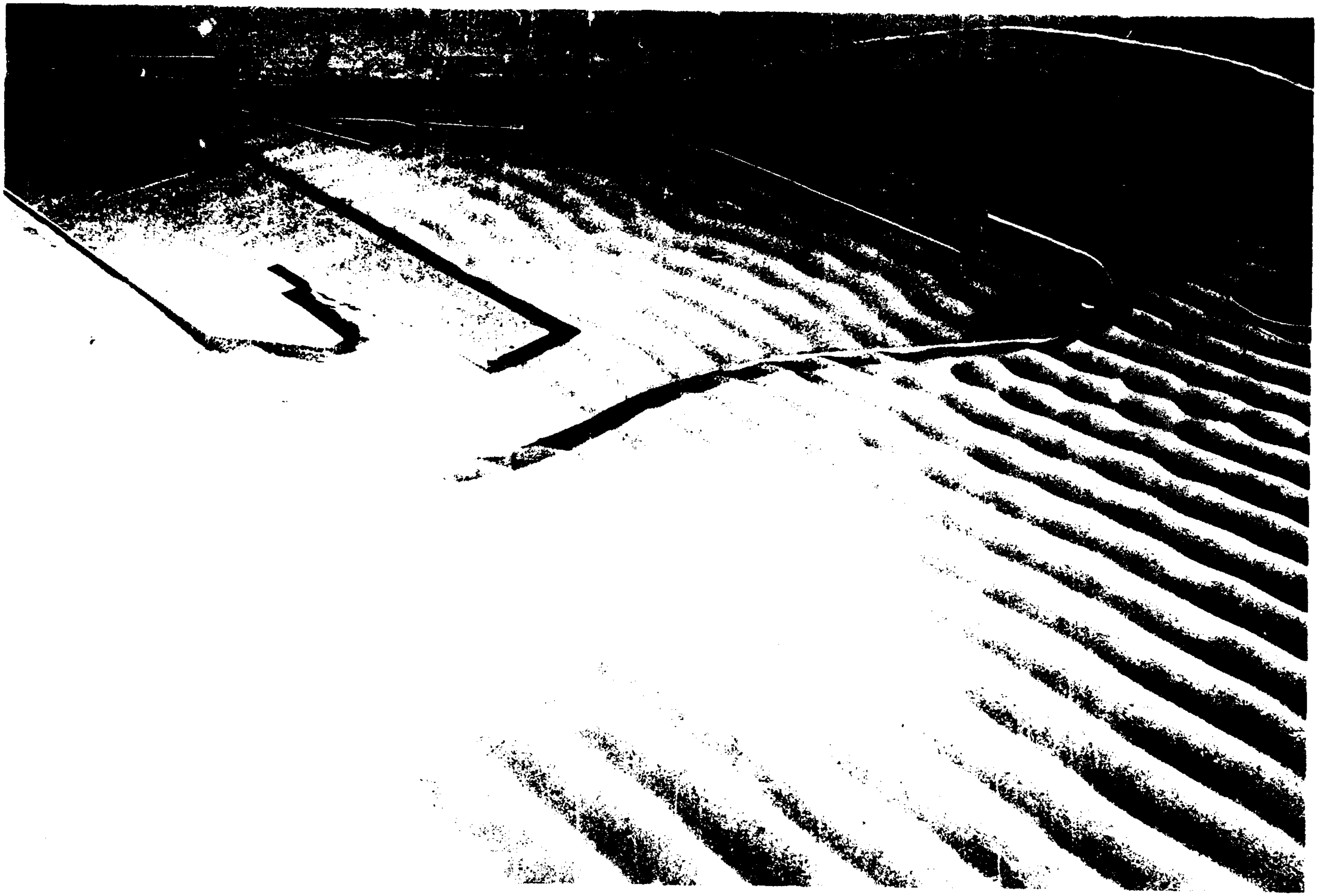

Photo 37. Typical wave patterns for Plan 6; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

Photo 38. Typical wave patterns for Plan 7; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

Photo 39. Typical wave patterns for Plan 8; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

Photo 40. Typical wave patterns for *Plan 9*; 3.9-sec, 3.3-ft waves *from northeast*; +5.7 ft swl

Photo 41. Typical wave patterns for Plan 10; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

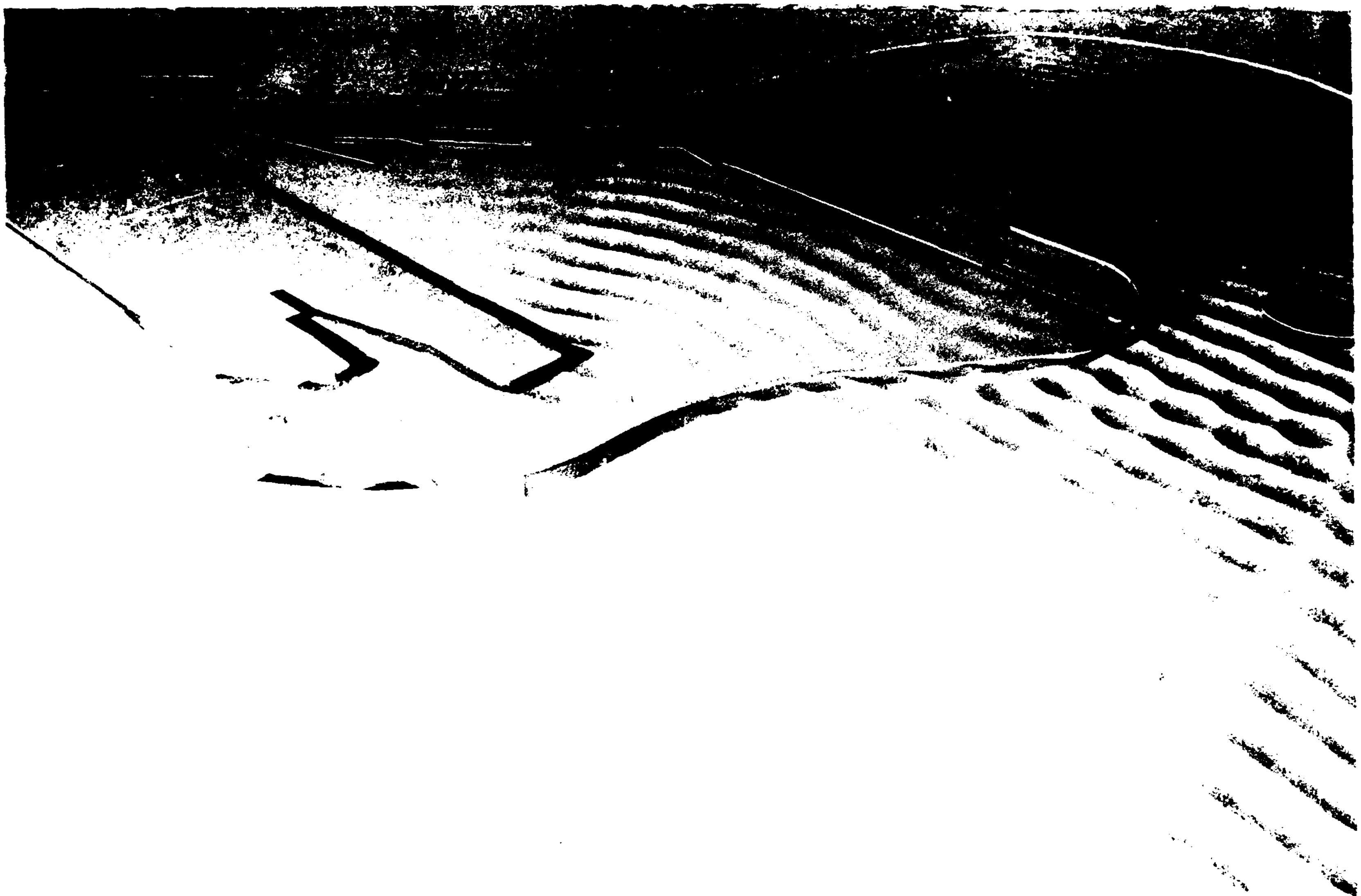

Photo 42. Typical wave patterns for Plan 11; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

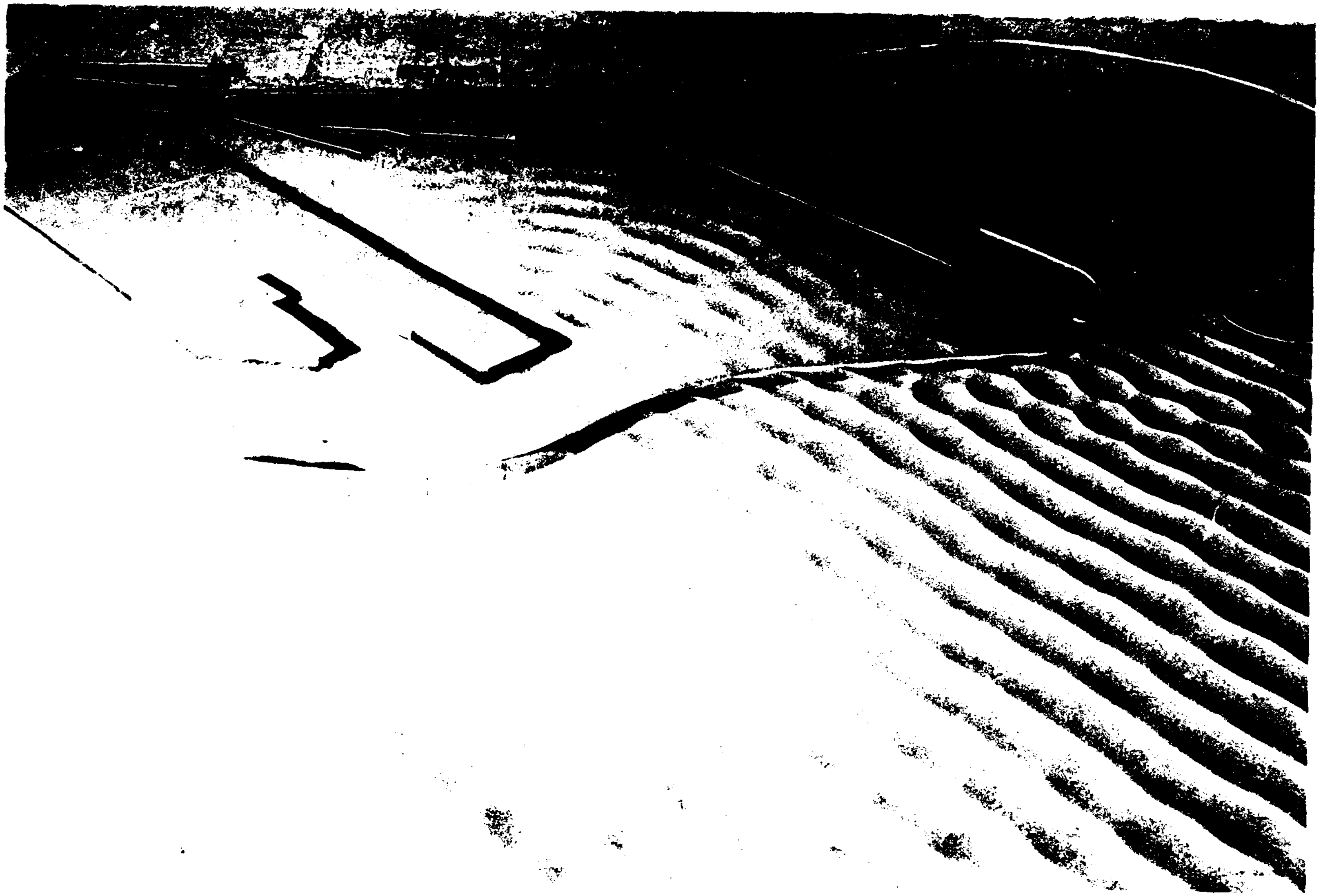

Photo 43. Typical wave patterns for Plan 12; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

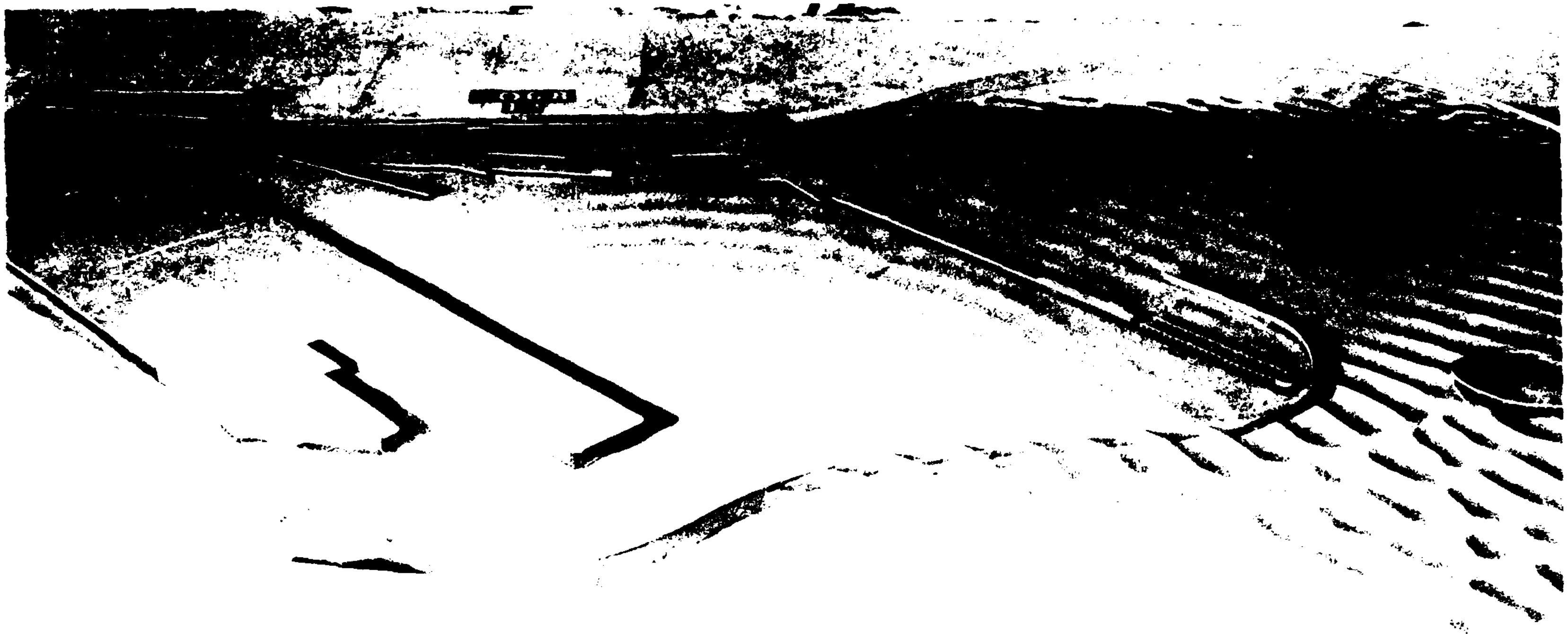

Photo 44. Typical wave patterns for Plan 13; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

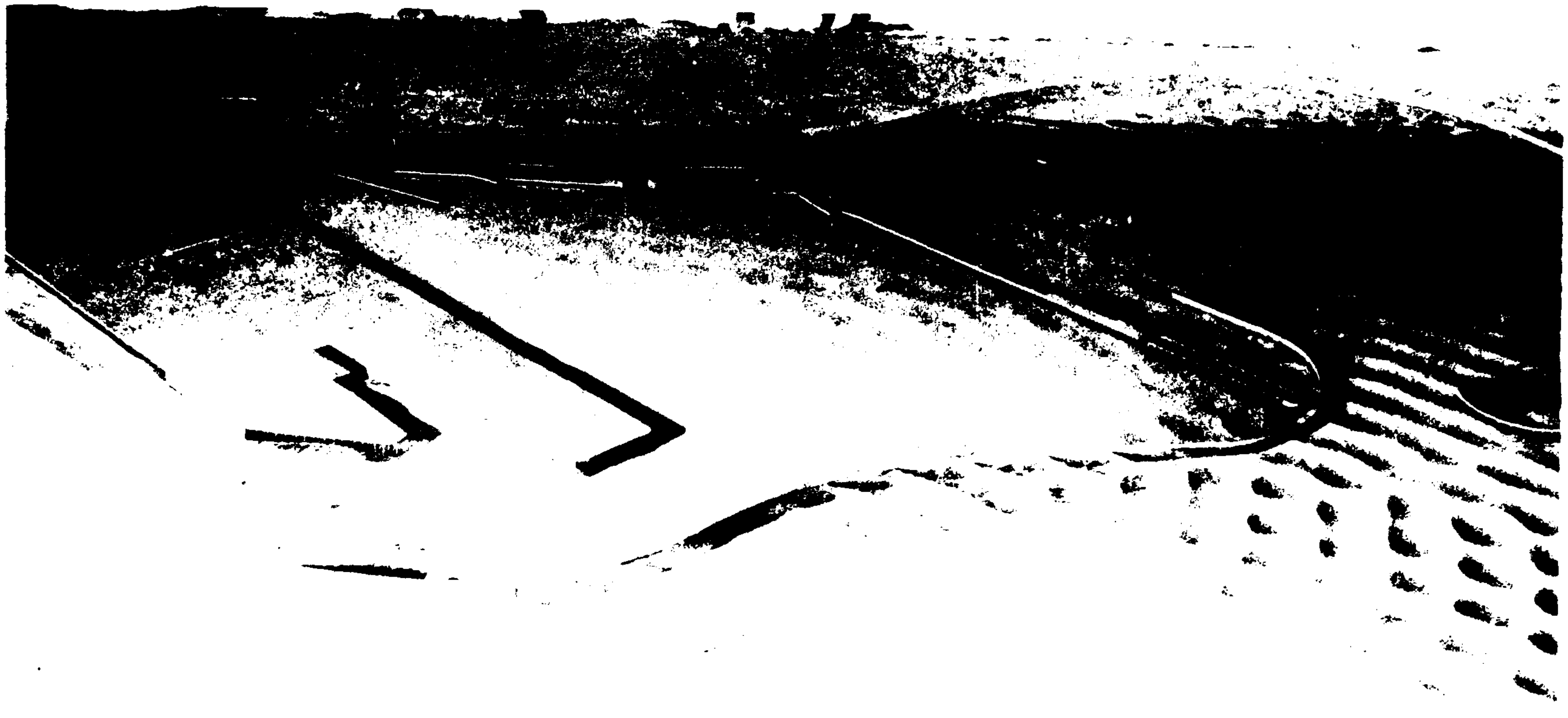

Photo 45. Typical wave patterns for Plan 14; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

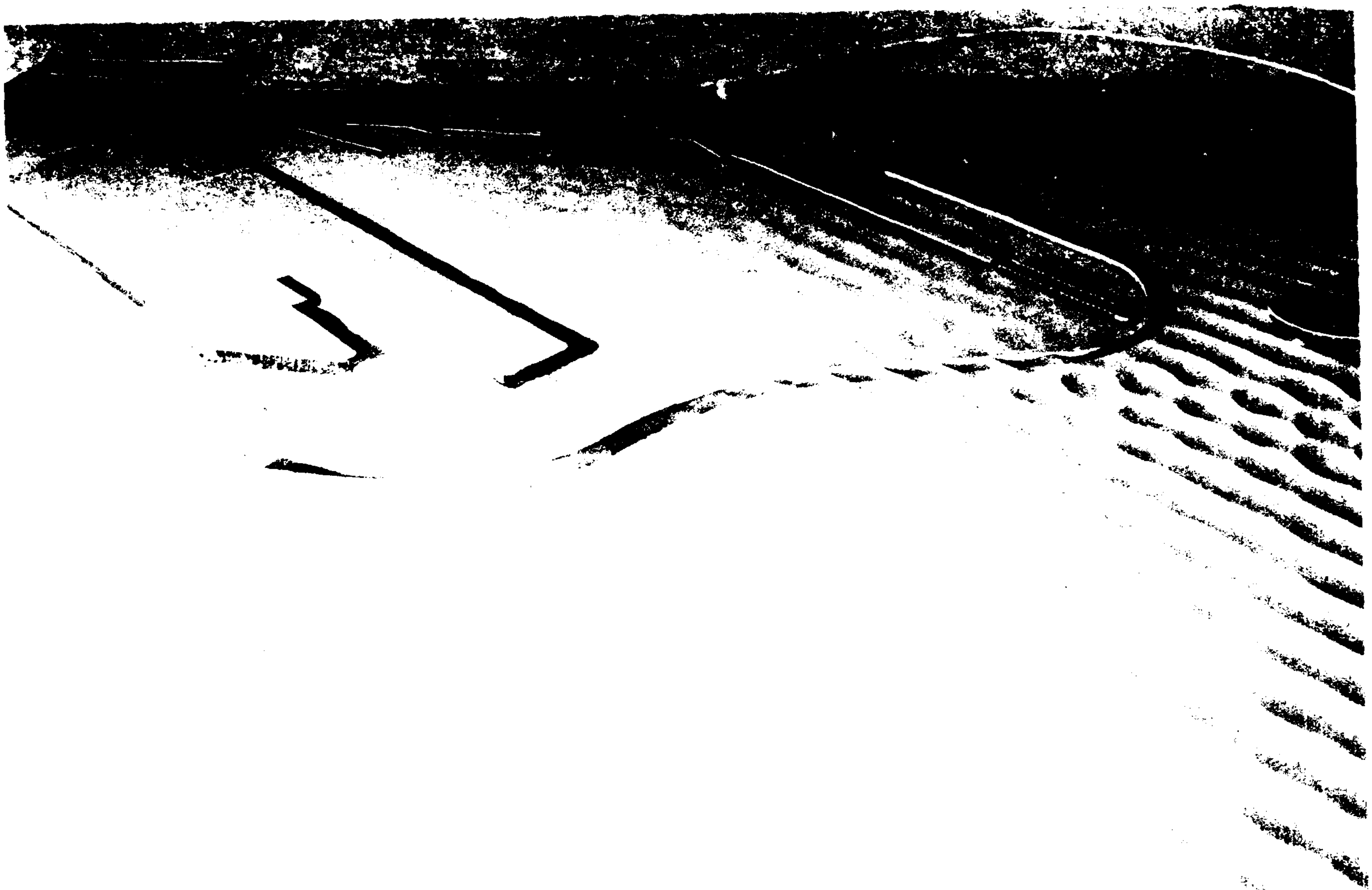

Photo 46. Typical wave patterns for Plan 15; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

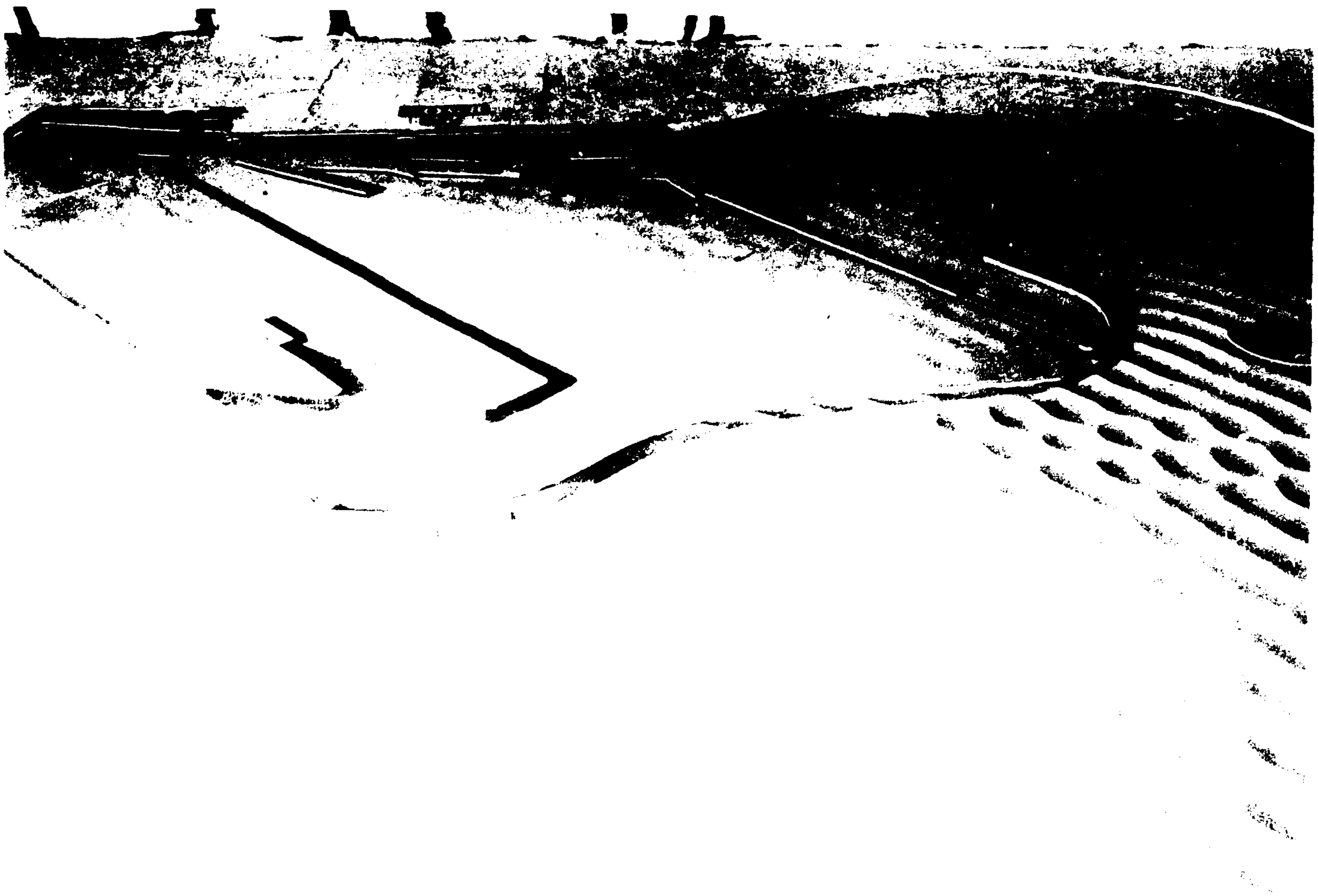

Photo 47. Typical wave patterns for Plan 16; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

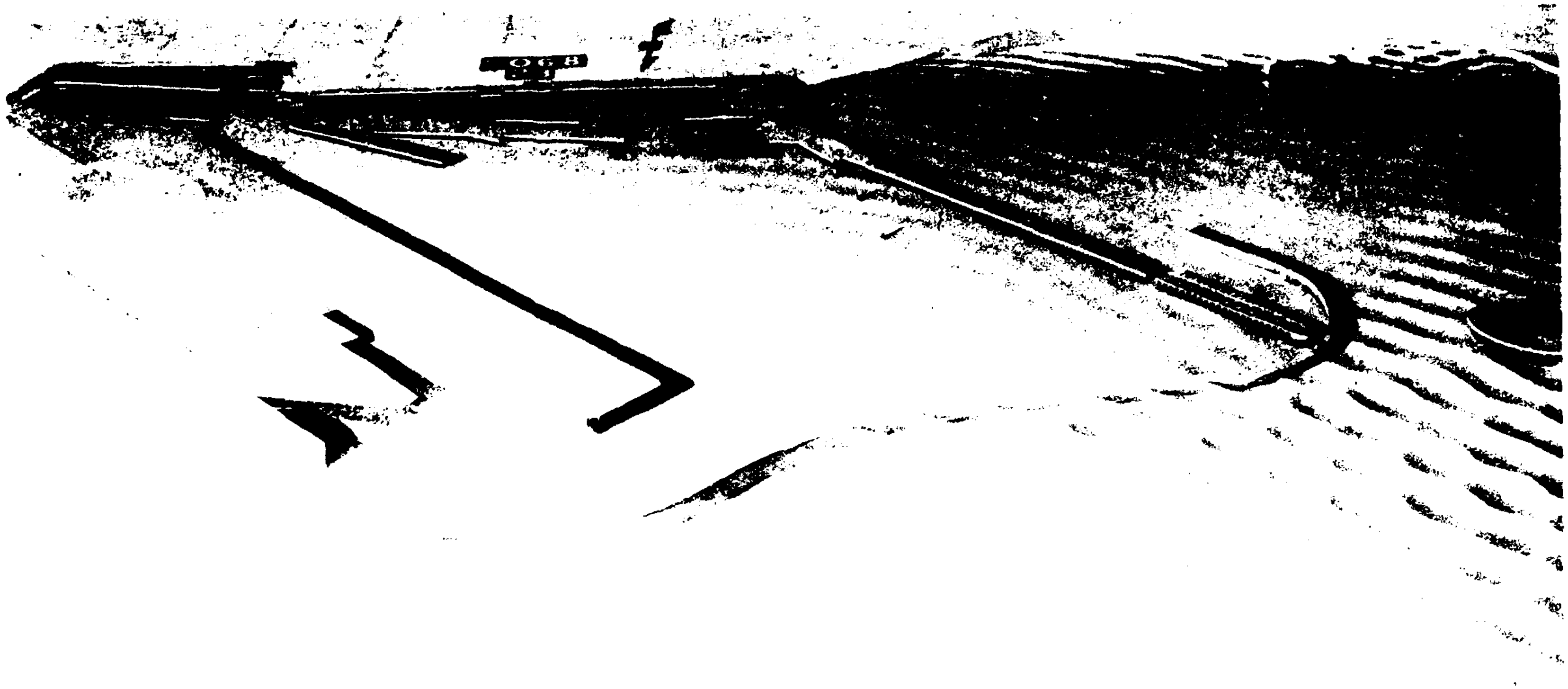

Photo 48. Typical wave patterns for Plan 17; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

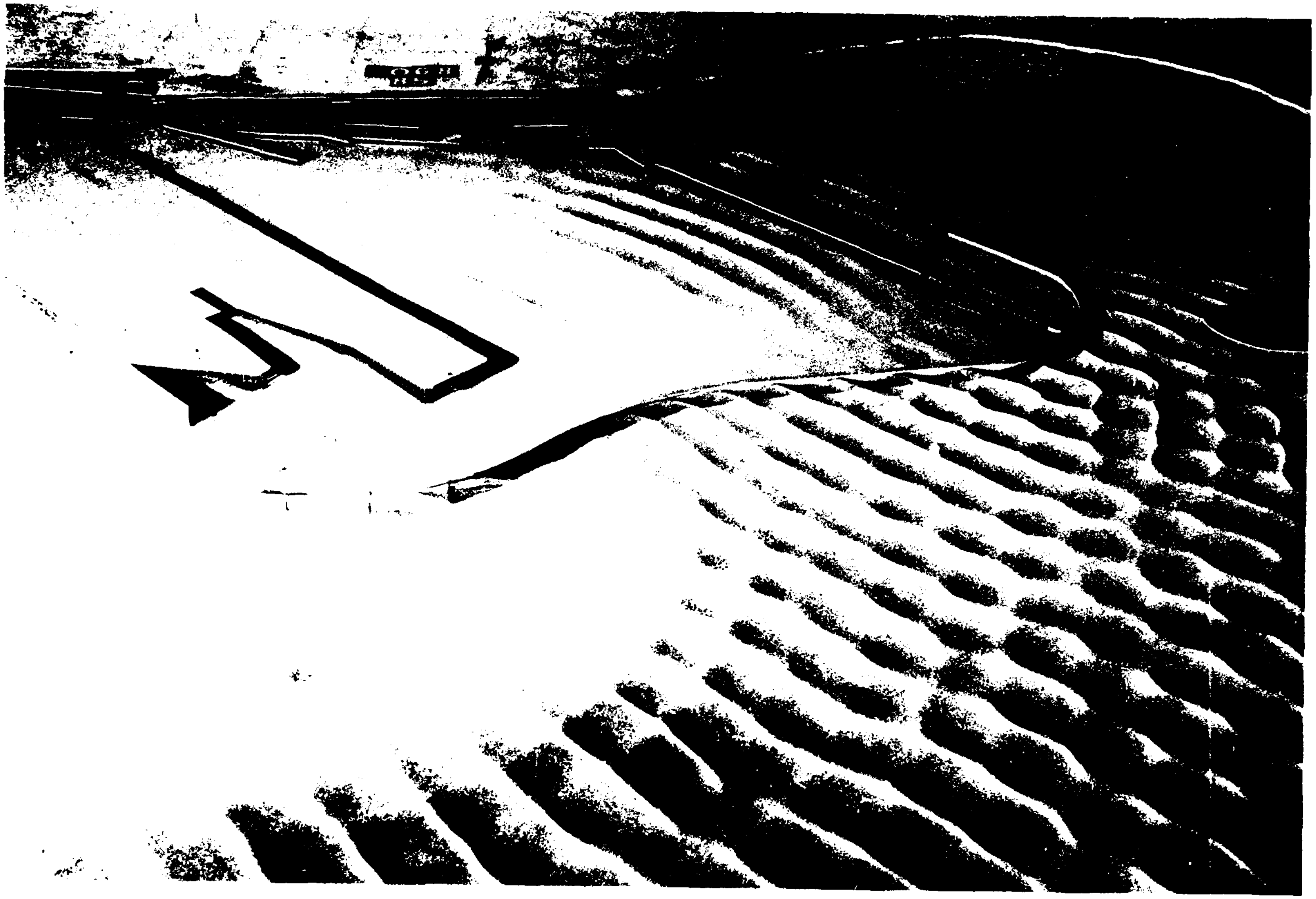

Photo 49. Typical wave patterns for Plan 18; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

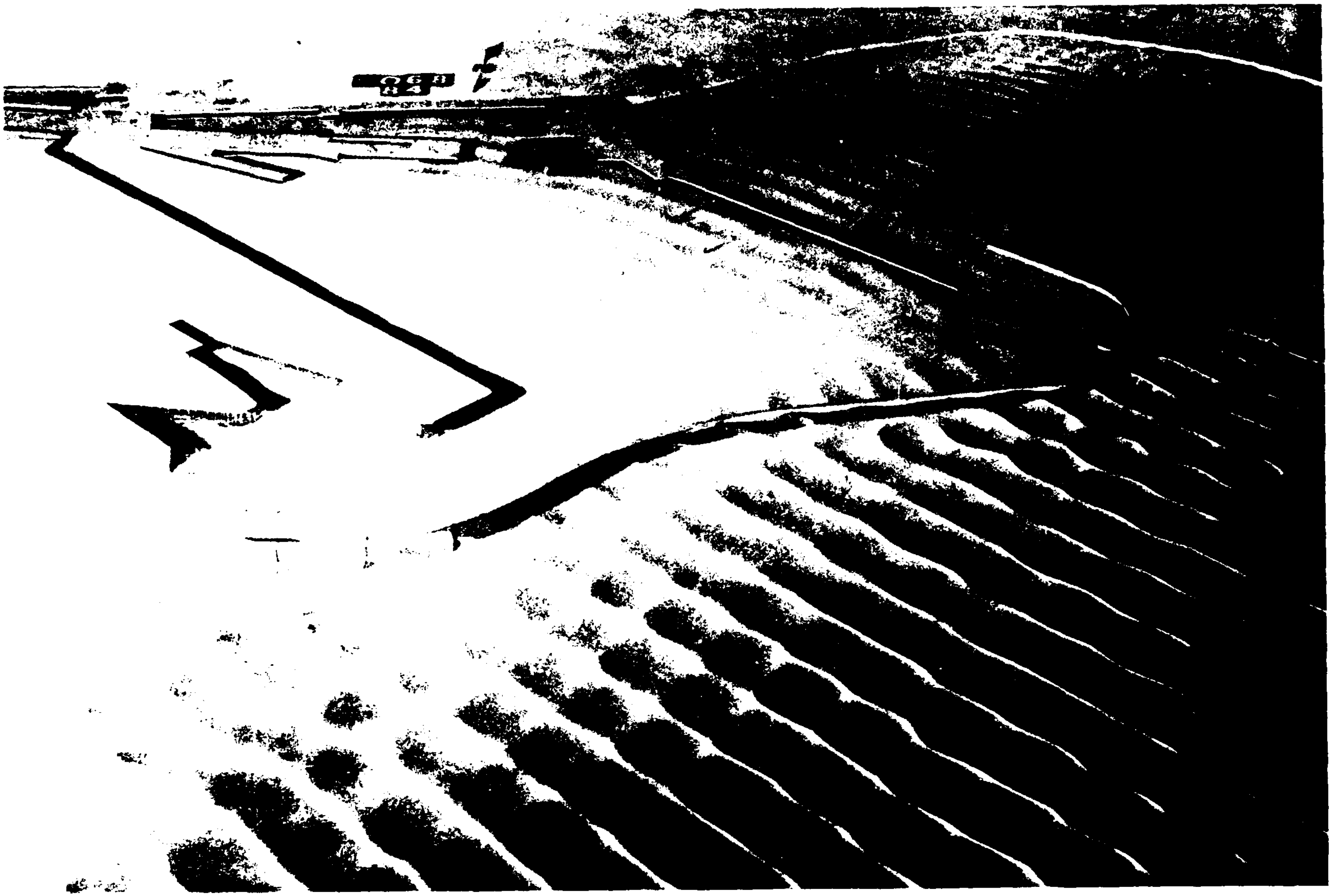

Photo 50. Typical wave patterns for Plan 19; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

Photo 51. Typical wave patterns for Plan 20; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

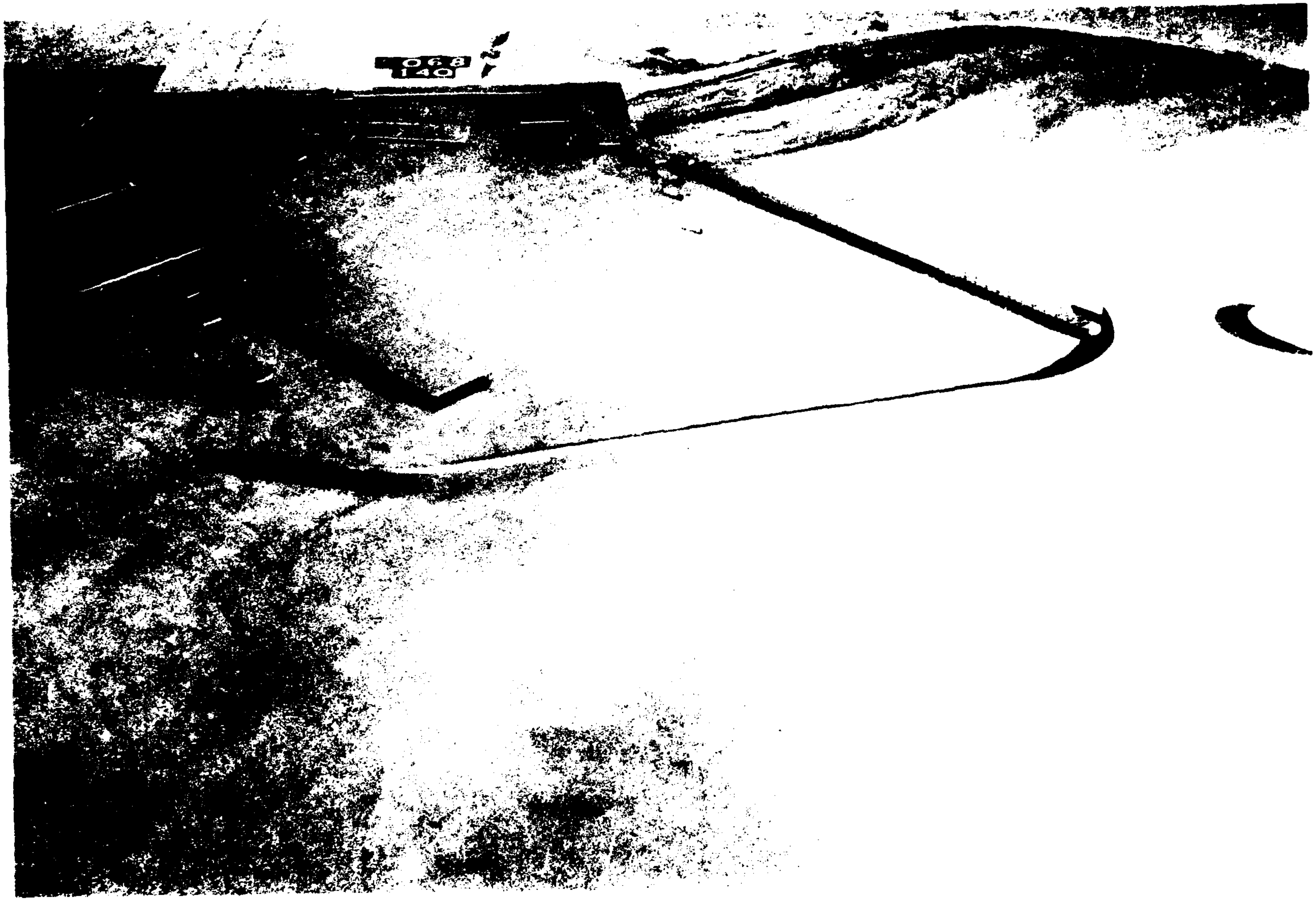

Photo 52. Typical wave patterns for Plan 21; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

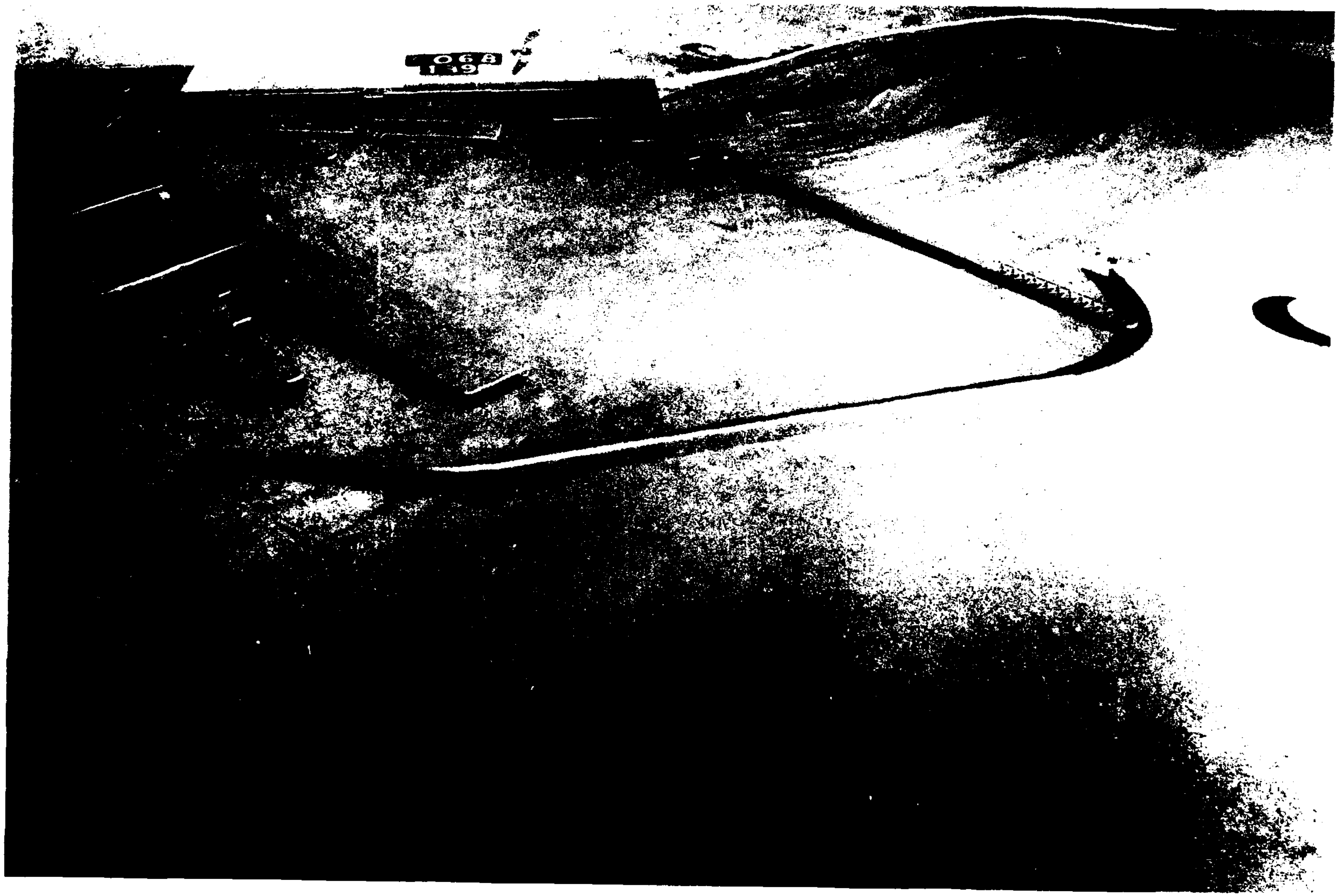

Photo 53. Typical wave patterns for Plan 22; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

Photo 54. Typical wave patterns for Plan 23; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

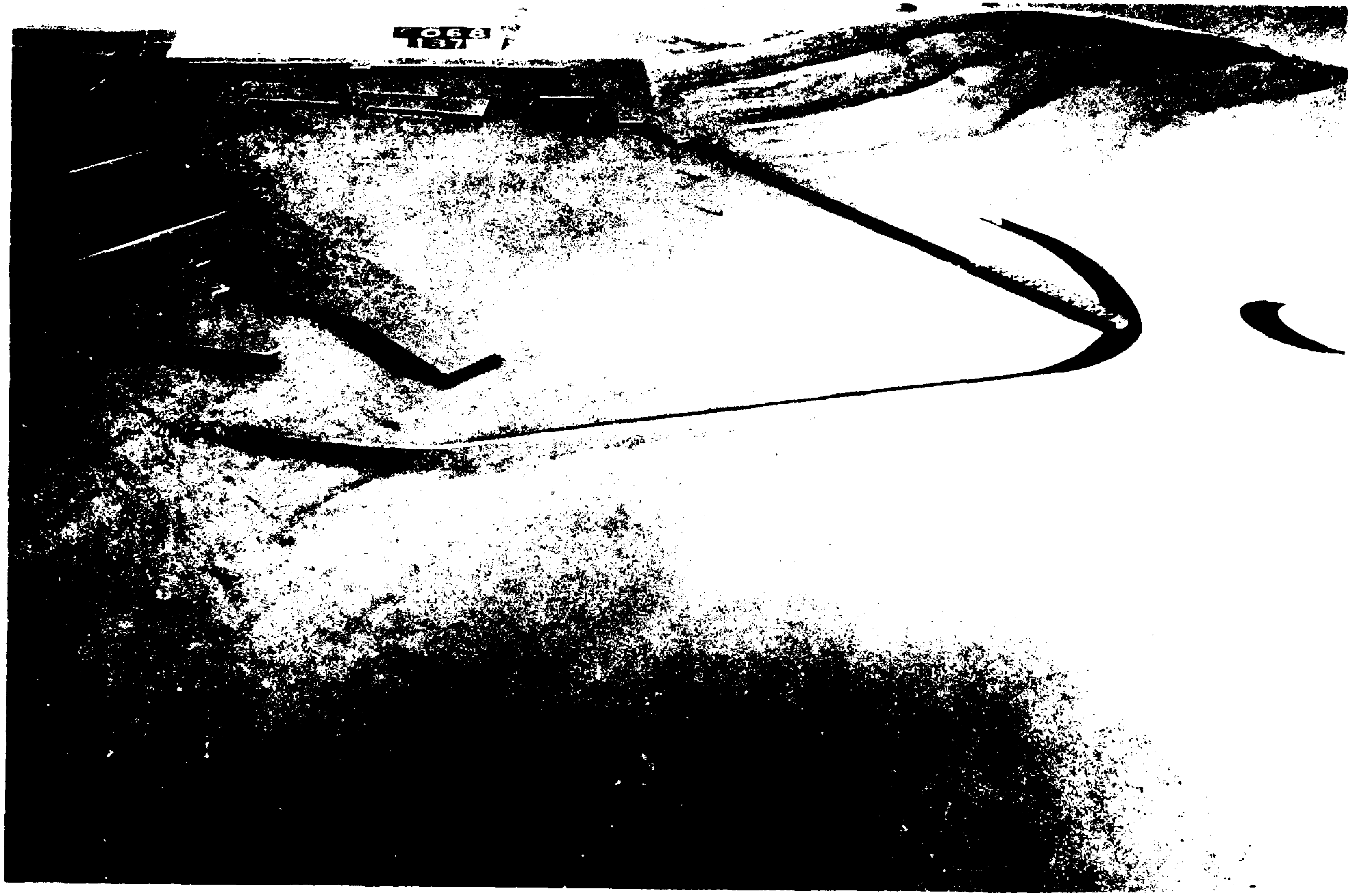

Photo 55. Typical wave patterns for Plan 24; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

Photo 56. Typical wave patterns for Plan 25; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

Photo 57. Typical wave patterns for Plan 26; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

Photo 58. Typical wave patterns for Plan 27; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

Photo 59. Typical wave patterns for Plan 28; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

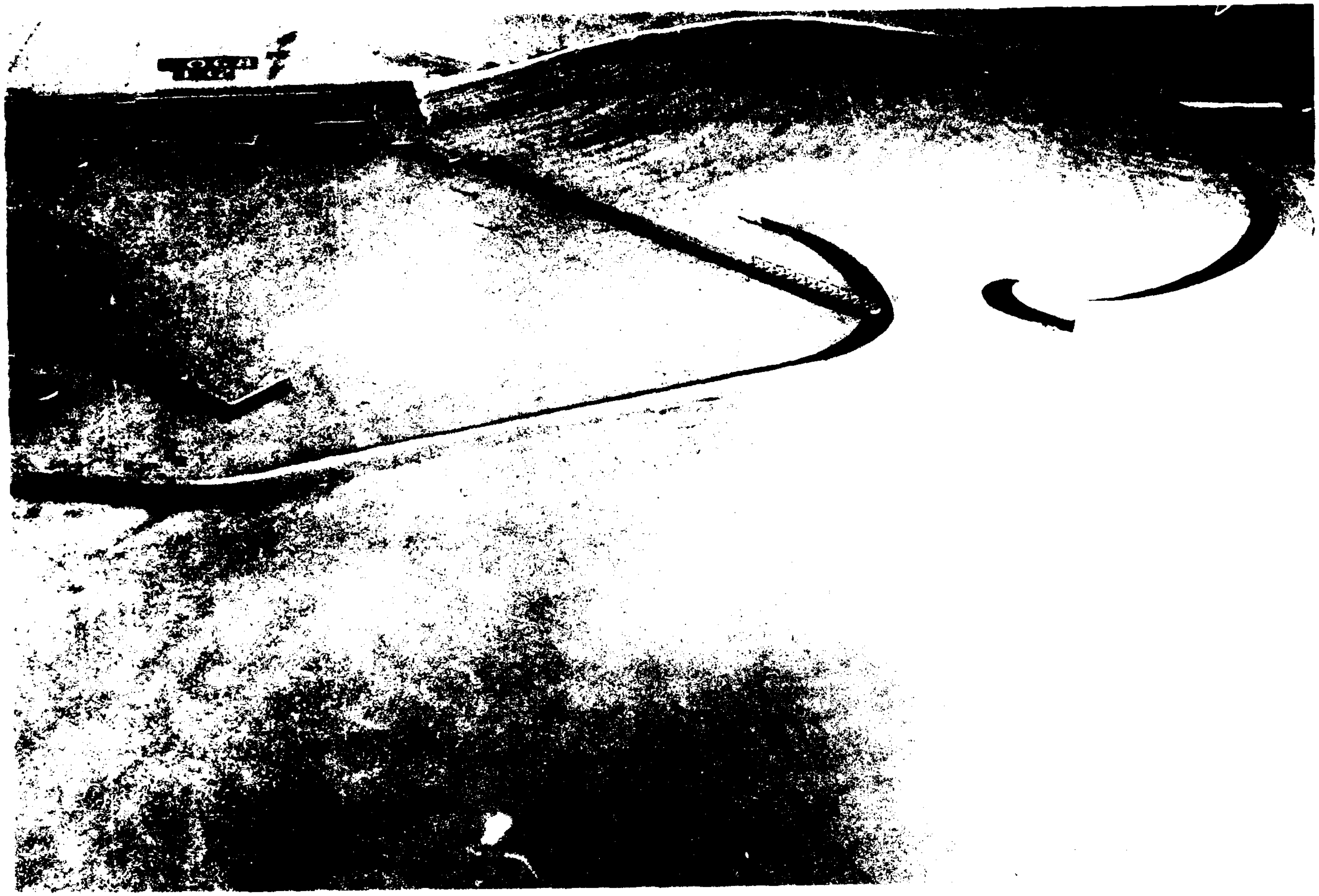

Photo 60. Typical wave patterns for Plan 29; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

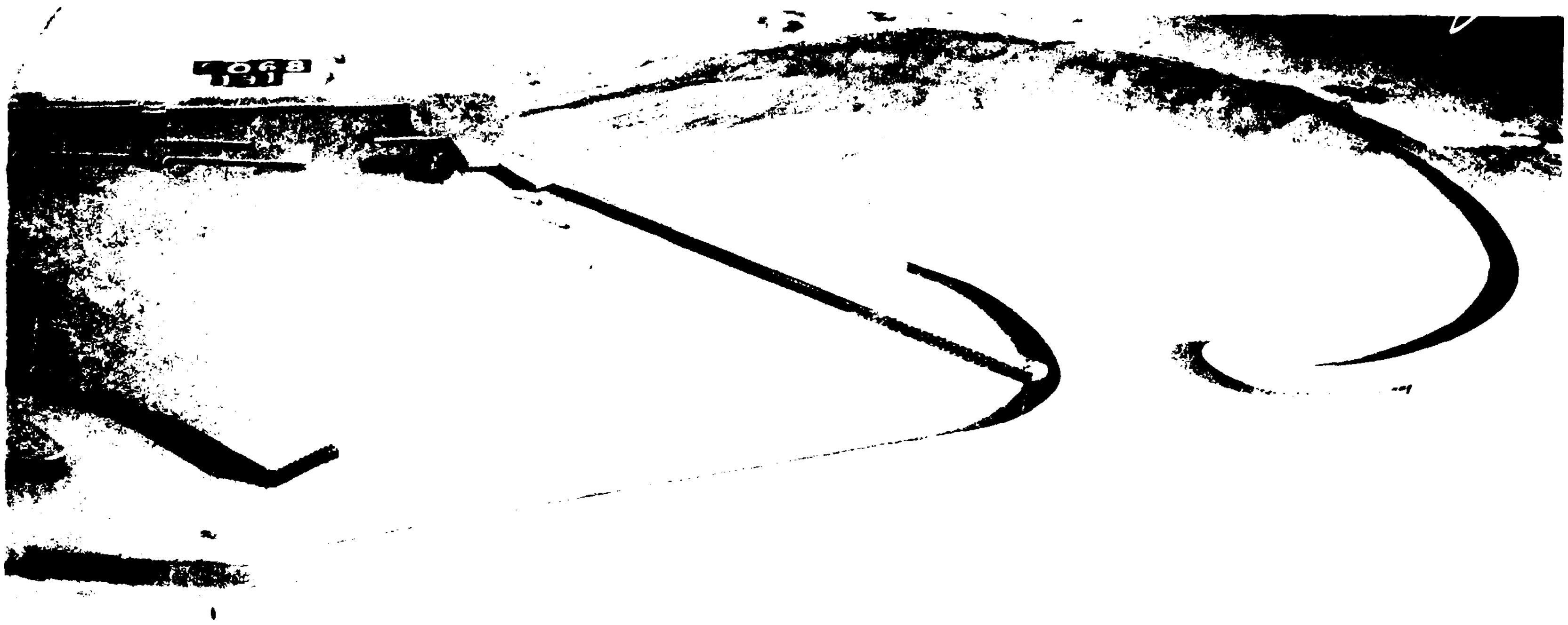

Photo 61. Typical wave patterns for Plan 30; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

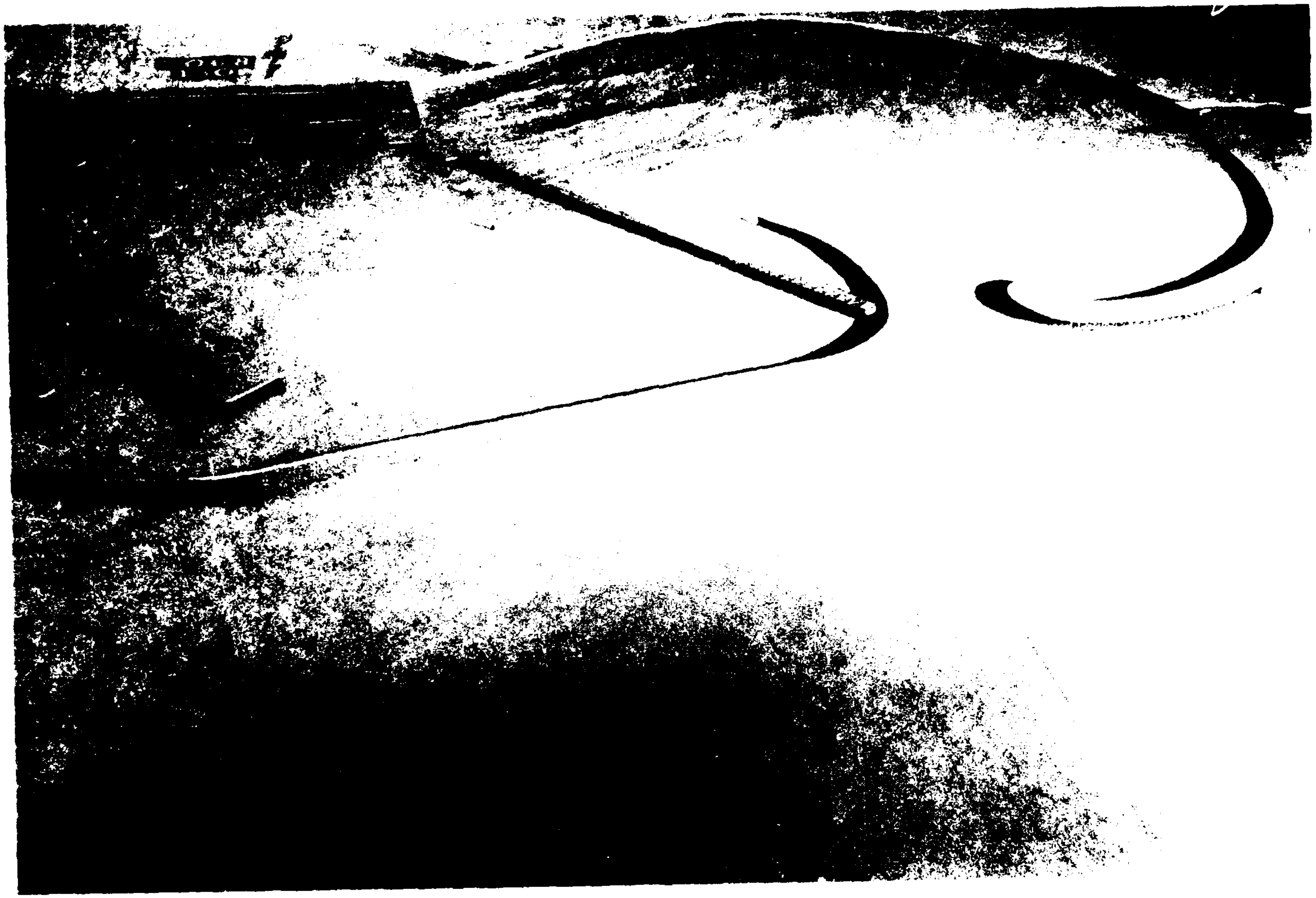

Photo 62. Typical wave patterns for Plan 31; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

Photo 63. Typical wave patterns for Plan 32; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

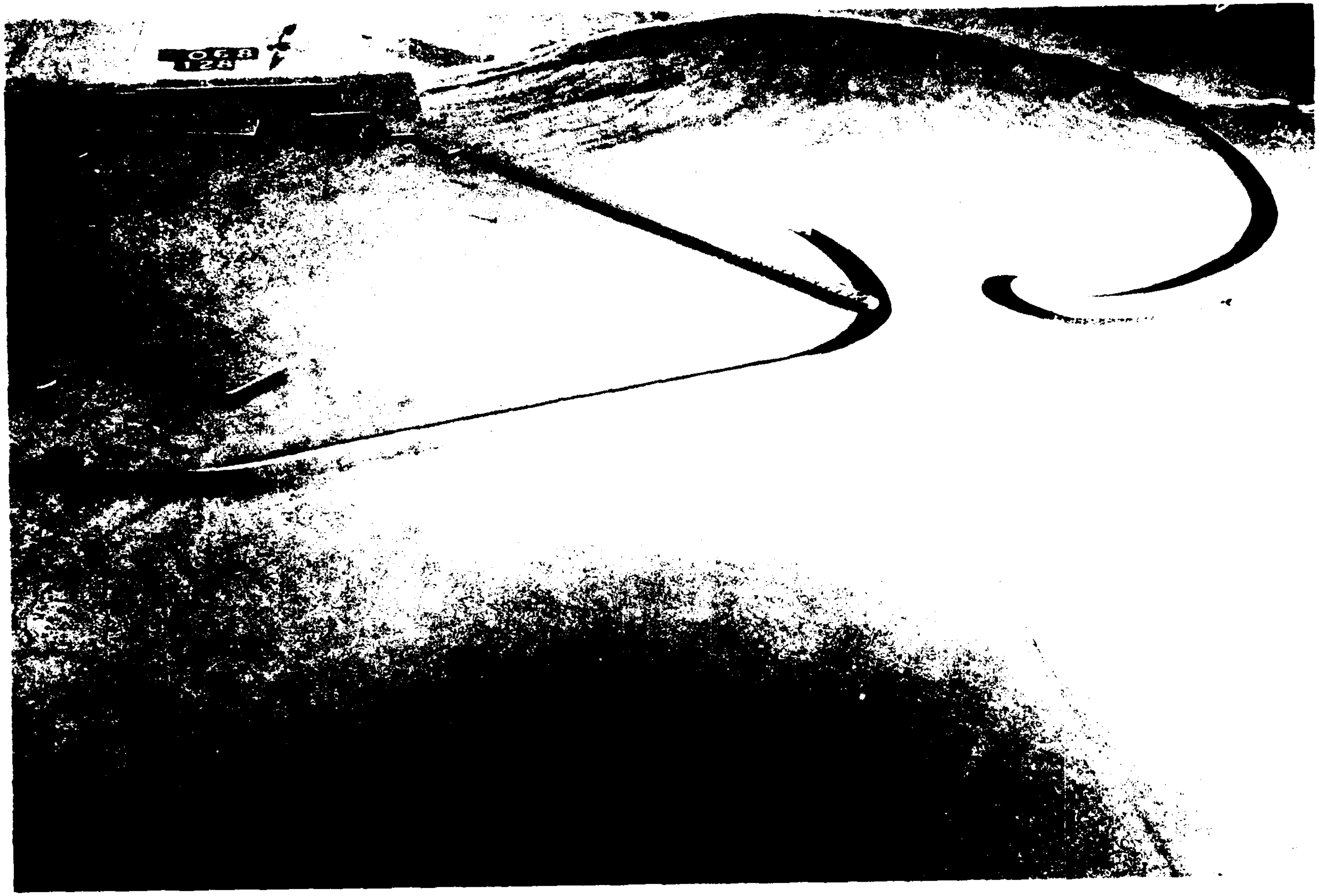

Photo 64. Typical wave patterns for Plan 33; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

Photo 65. Typical wave patterns for Plan 23; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

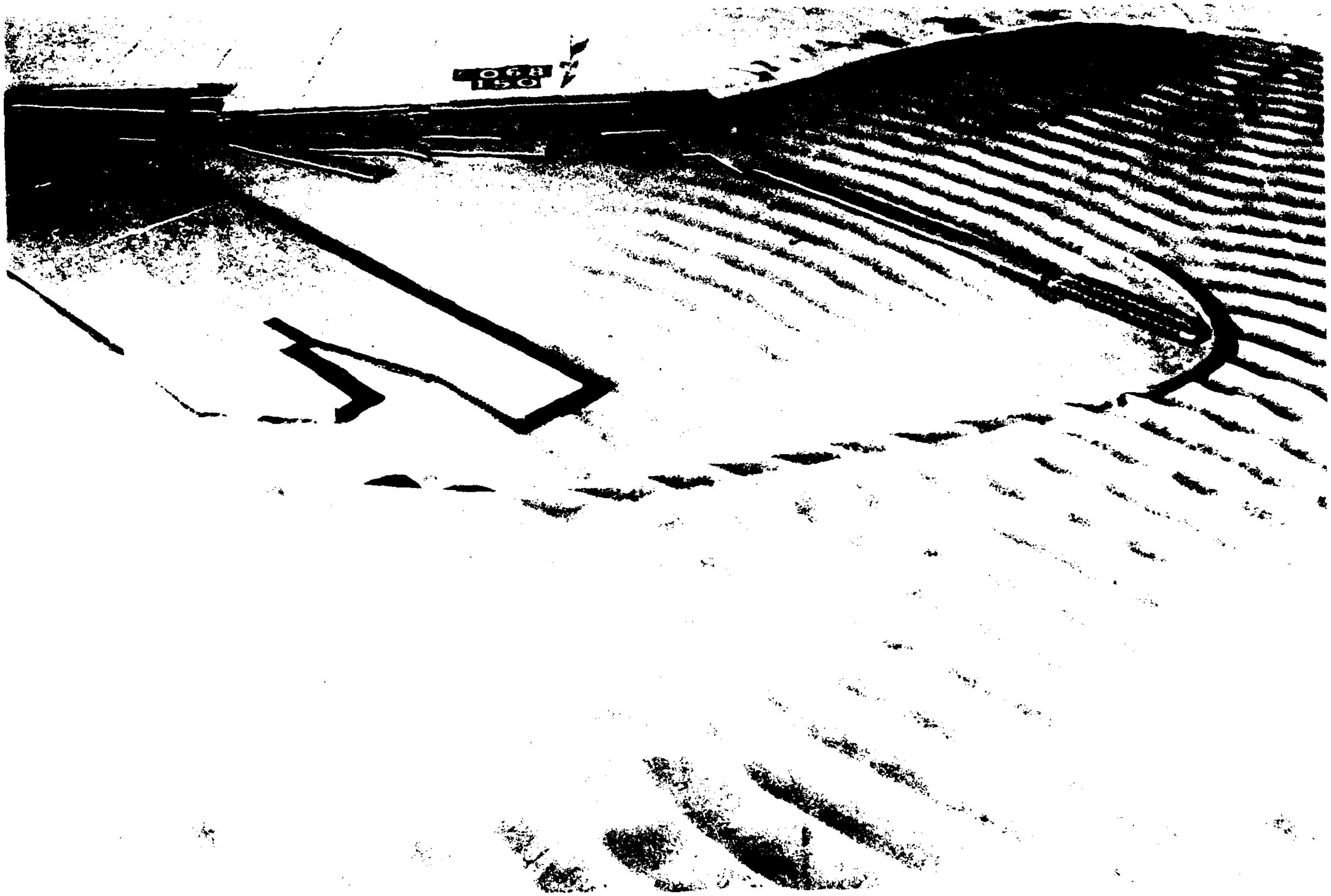

Photo 66. Typical wave patterns for Plan 34; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

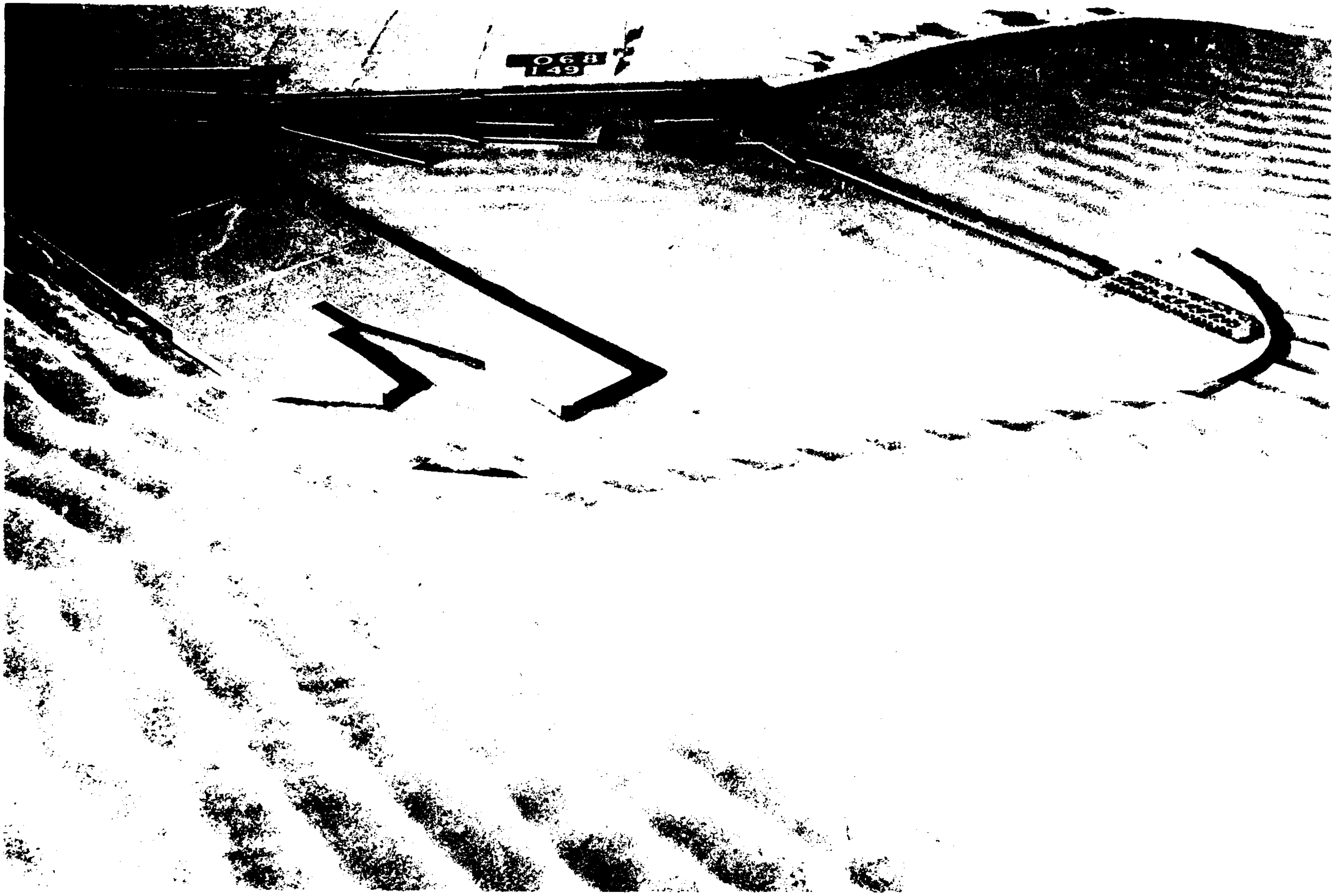

Photo 67. Typical wave patterns for Plan 35; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

Photo 68. Typical wave patterns for Plan 36; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

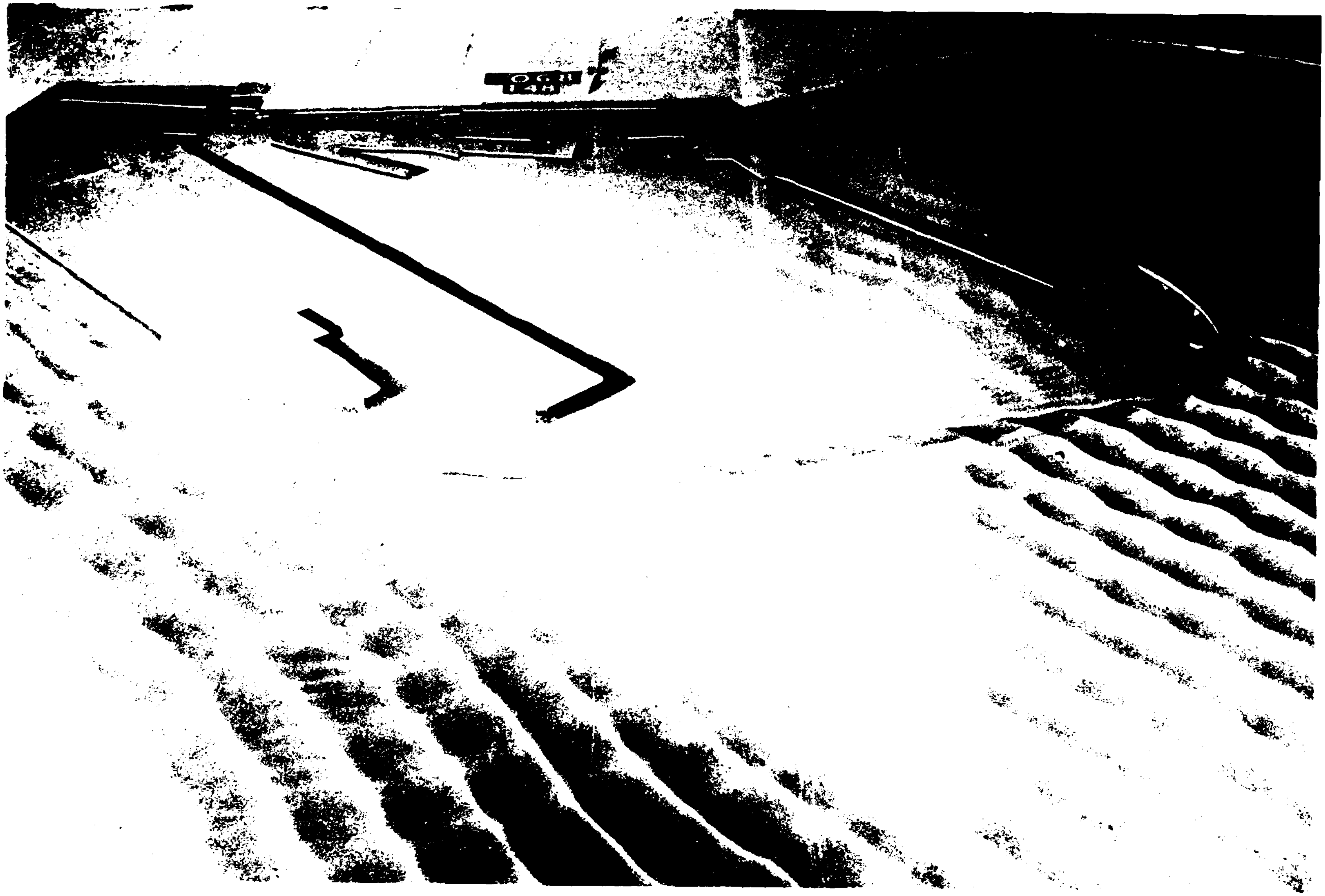

Photo 69. Typical wave patterns for Plan 37; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

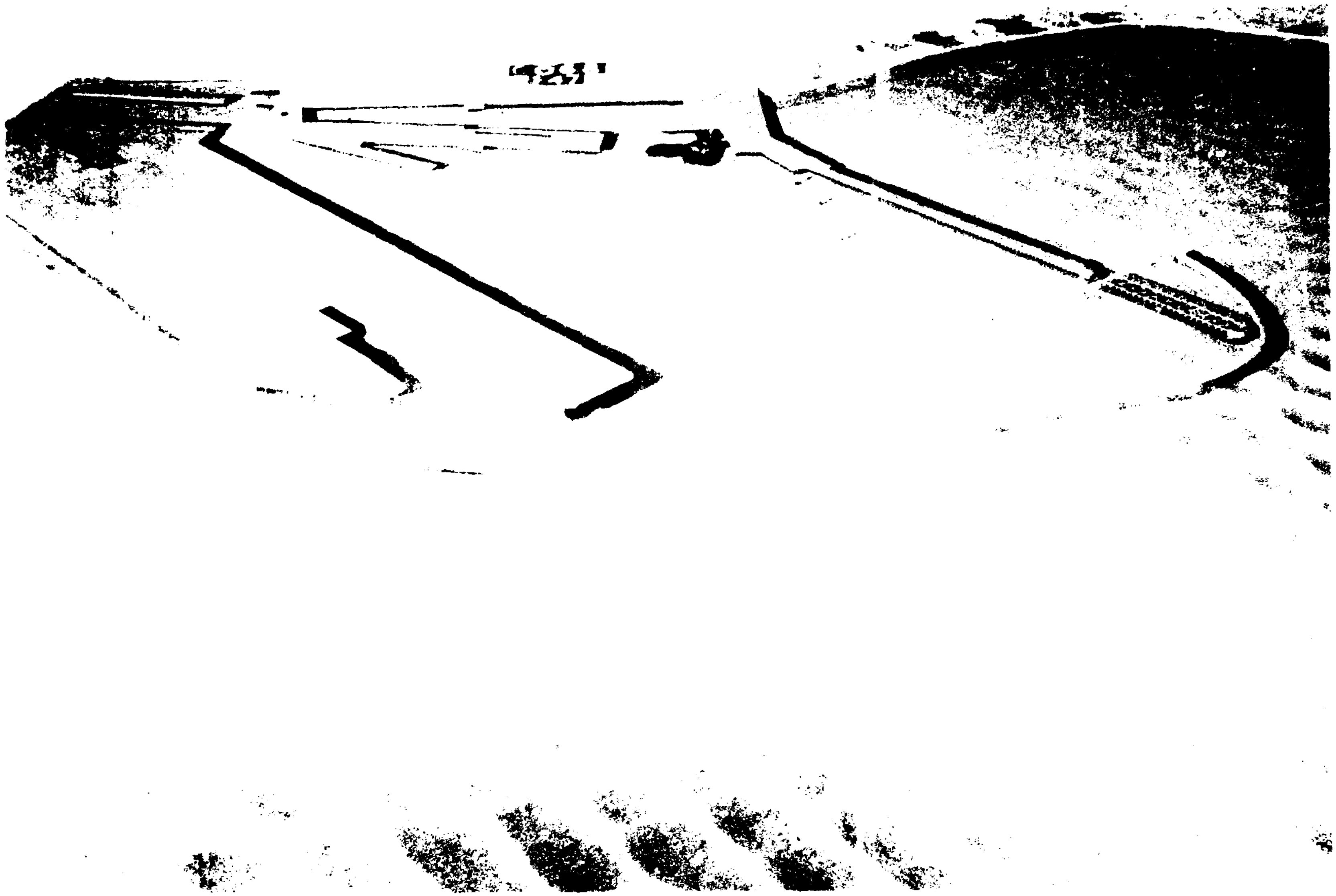

Photo 70. Typical wave patterns for Plan 38; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

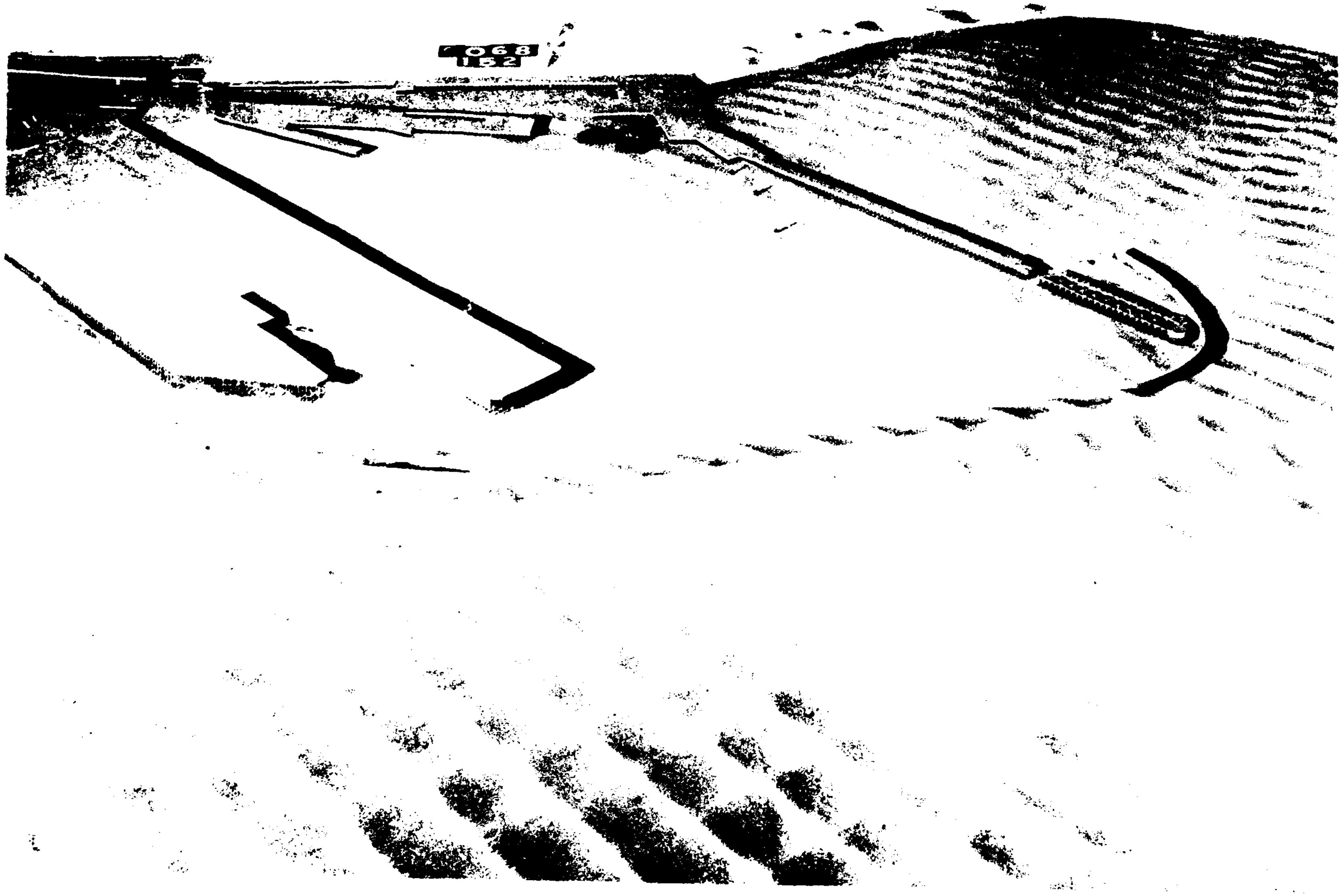

Photo 71. Typical wave patterns for Plan 39; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

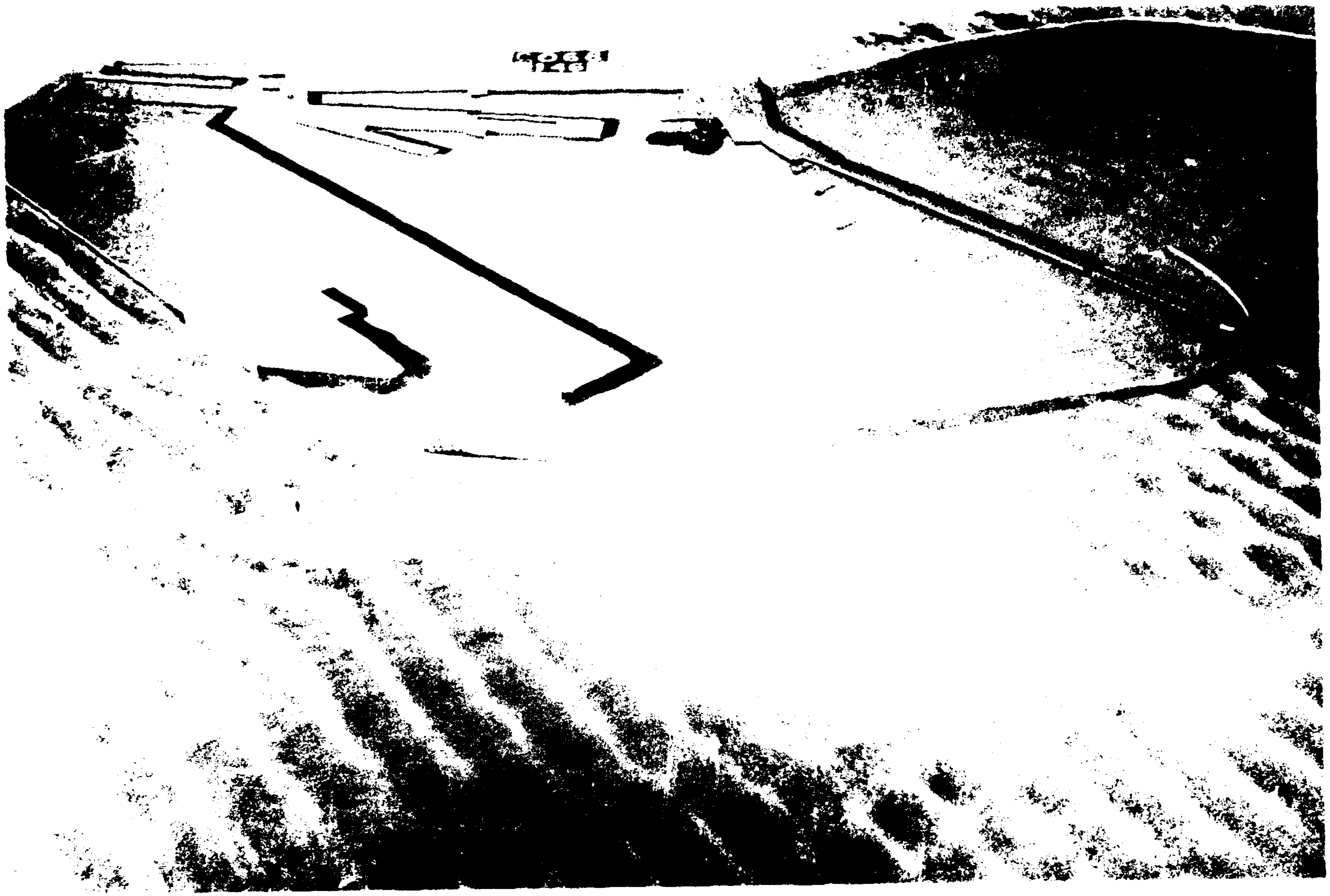

Photo 72. Typical wave patterns for Plan 38; 3.6-sec, 2-ft waves from northeast; +5.7 ft swl

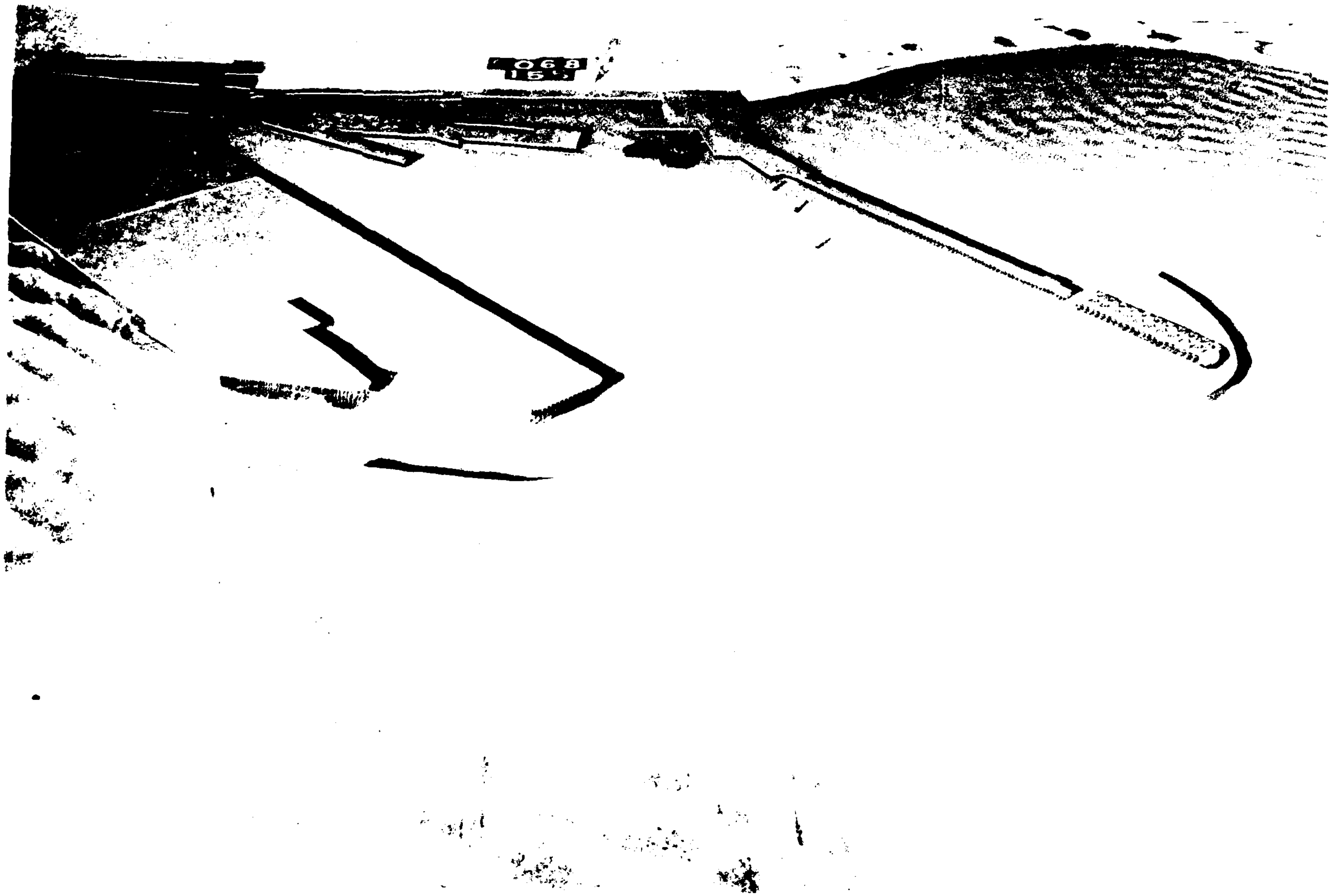

Photo 73. Typical wave patterns for Plan 38; 3.6-sec, 2.5-ft waves from north-northeast; +5.7 ft swl

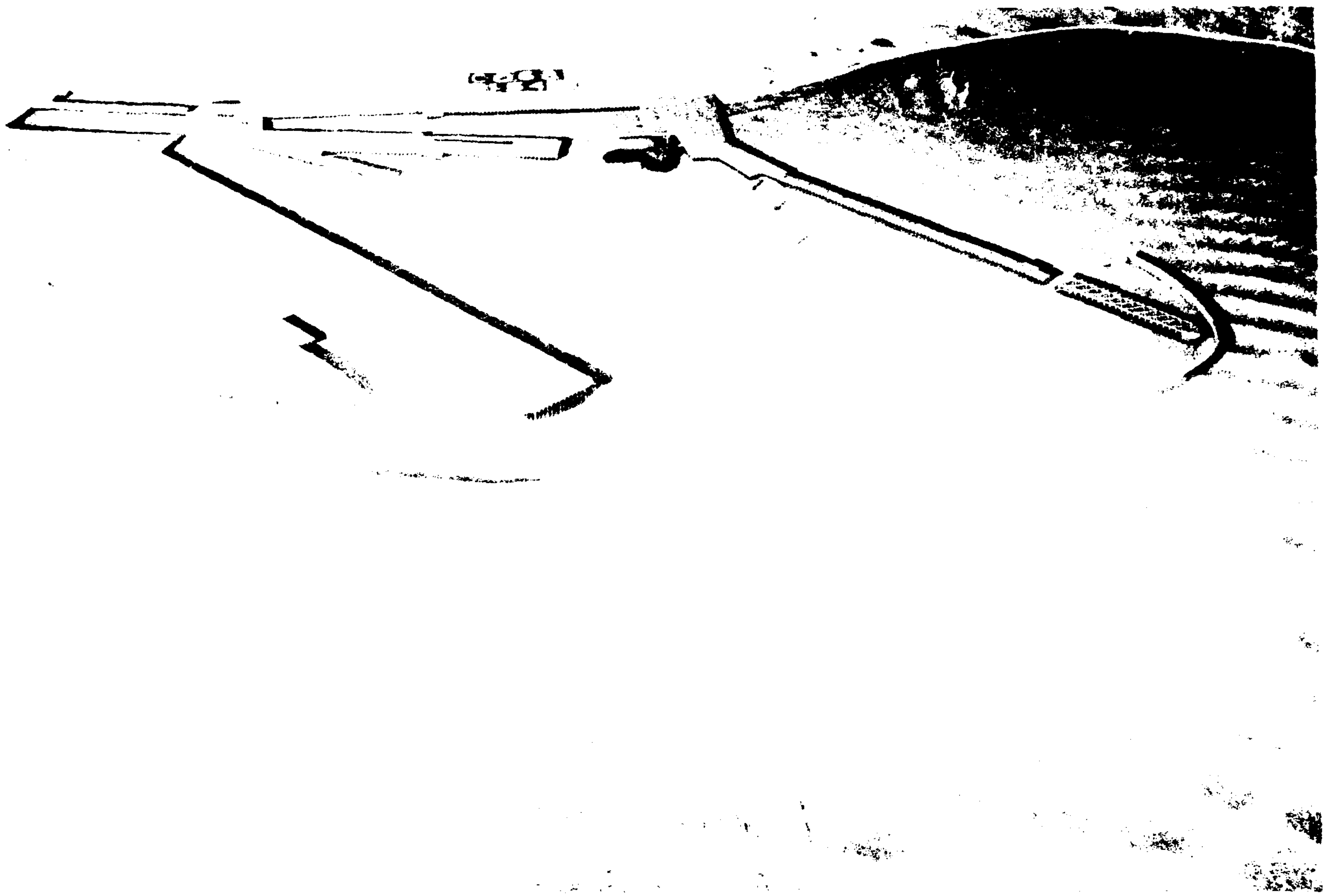

Photo 74. Typical wave patterns for Plan 38; 4.2-sec, 4.8-ft waves from north-northeast; +5.7 ft swl

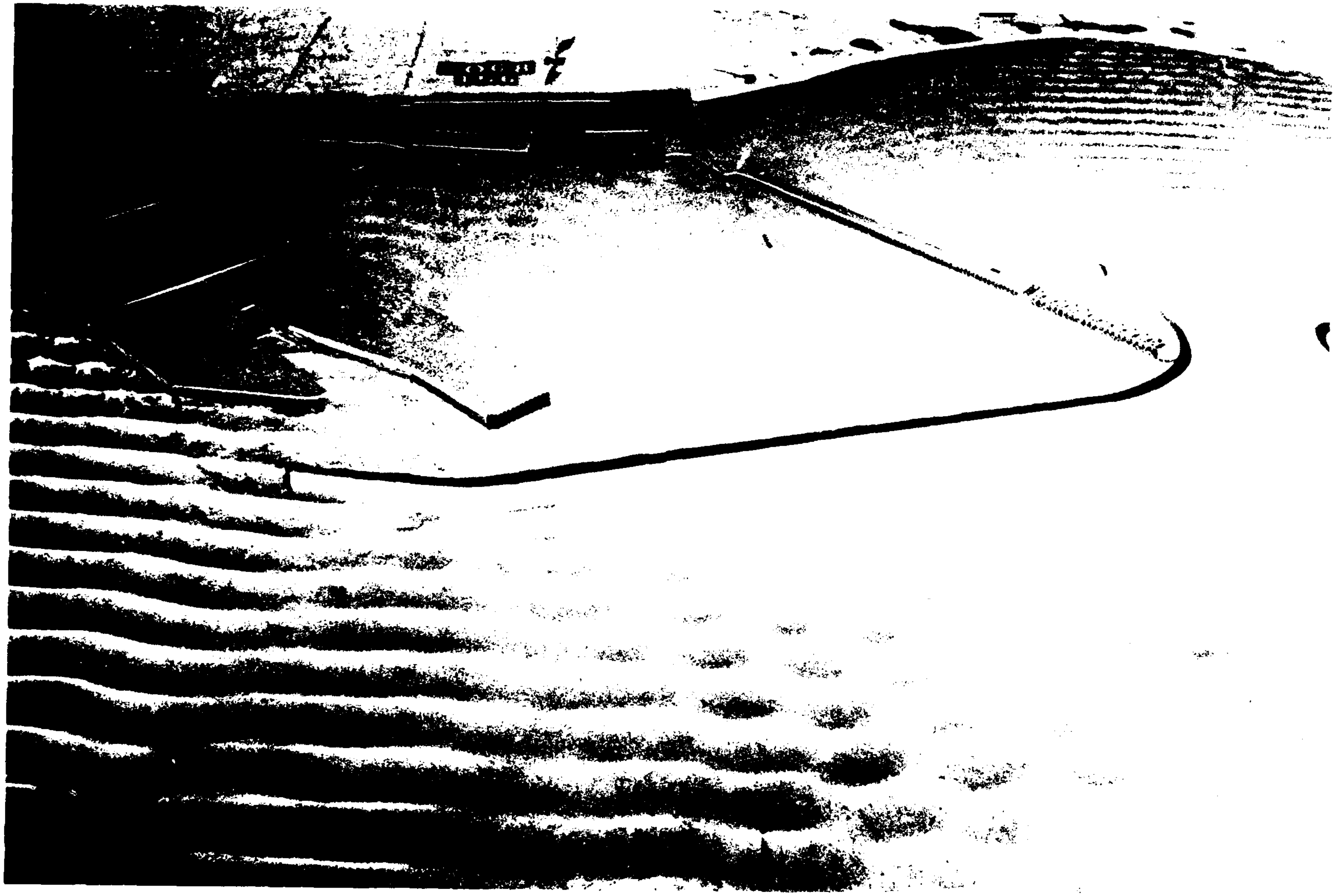

Photo 75. Typical wave patterns for Plan 38; 3.6-sec, 2.0-ft waves from north; +5.7 ft swl

Photo 76. Typical wave patterns for Plan 38; 3.6-sec, 3.1-ft waves from north; +5.7 ft swl

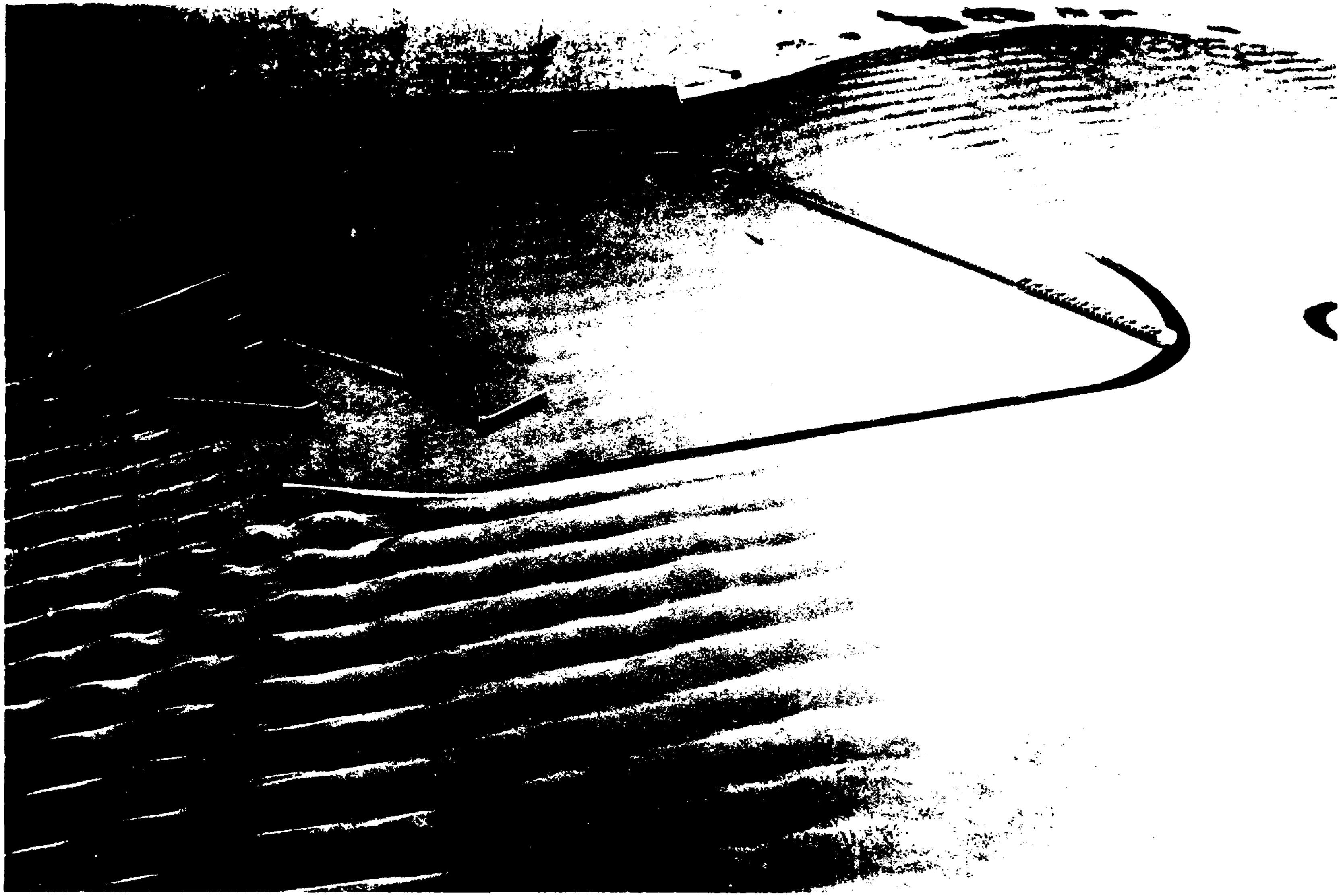

Photo 77. Typical wave patterns for Plan 38; 3.6-sec, 2-ft waves from north-northwest; +5.7 ft swl

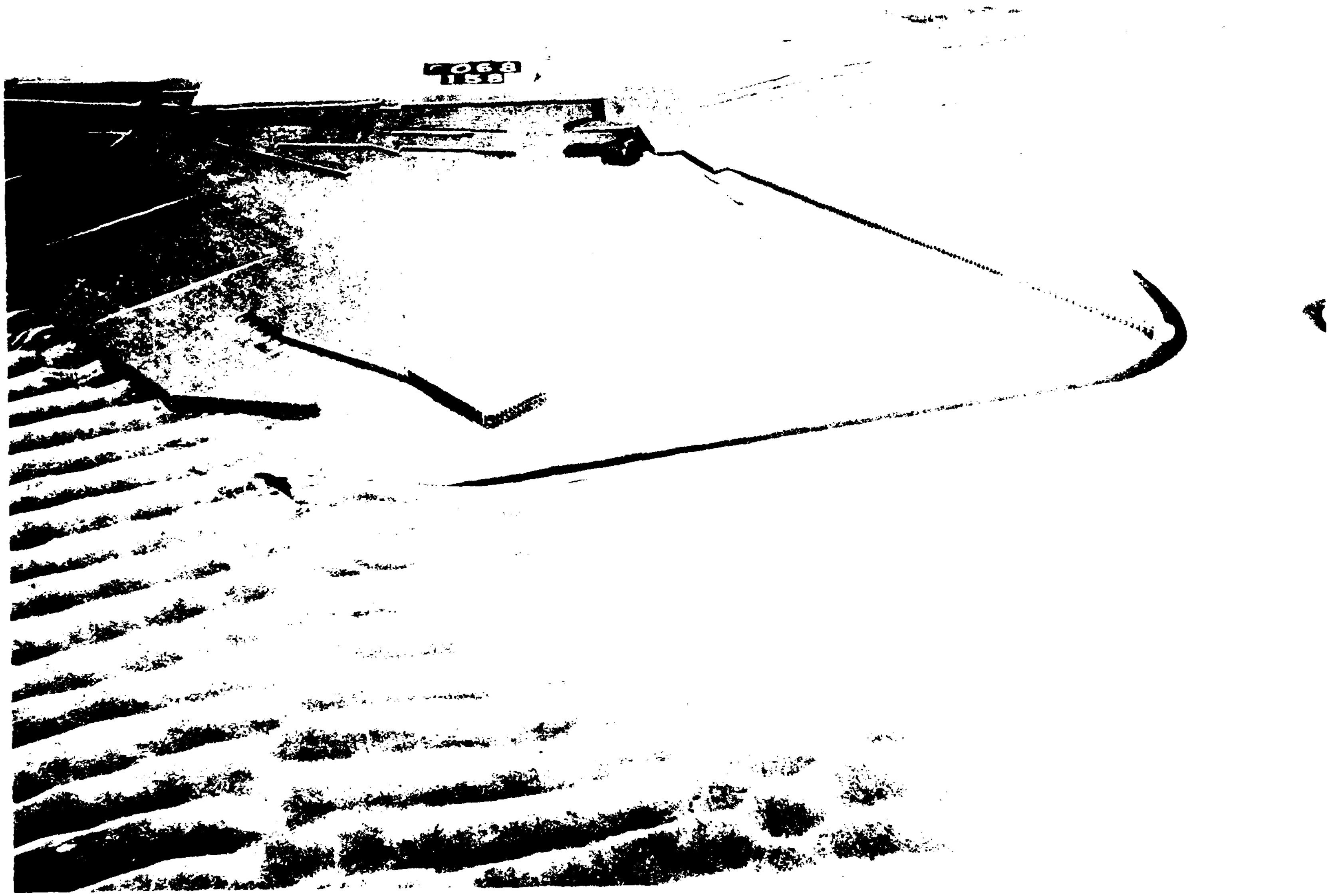

Photo 78. Typical wave patterns for Plan 38; 3.6-sec, 3.3-ft waves from north-northwest; +5.7 ft swl

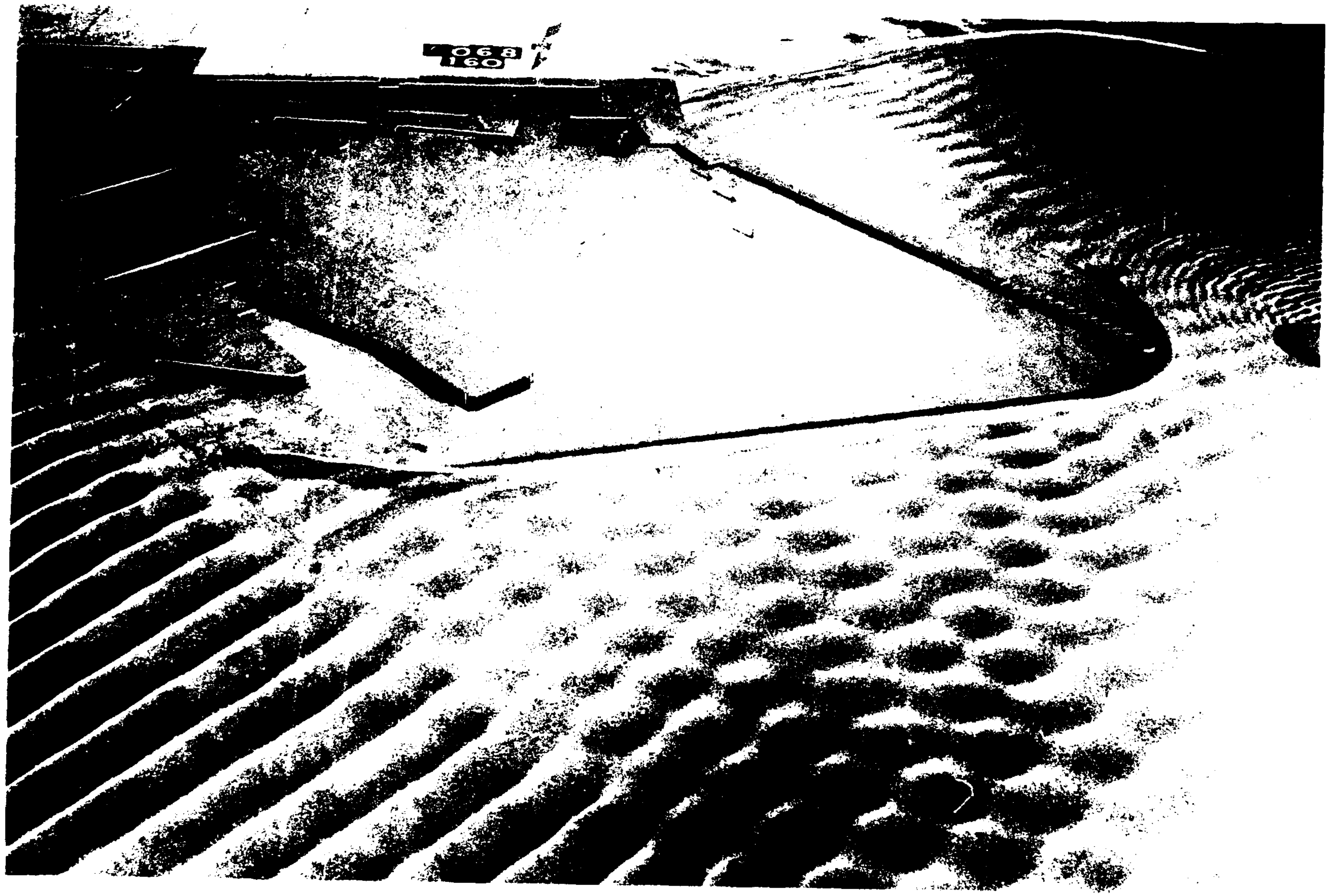

Photo 79. Typical wave patterns for Plan 38; 3.6-sec, 2-ft waves from northwest; +5.7 ft swl

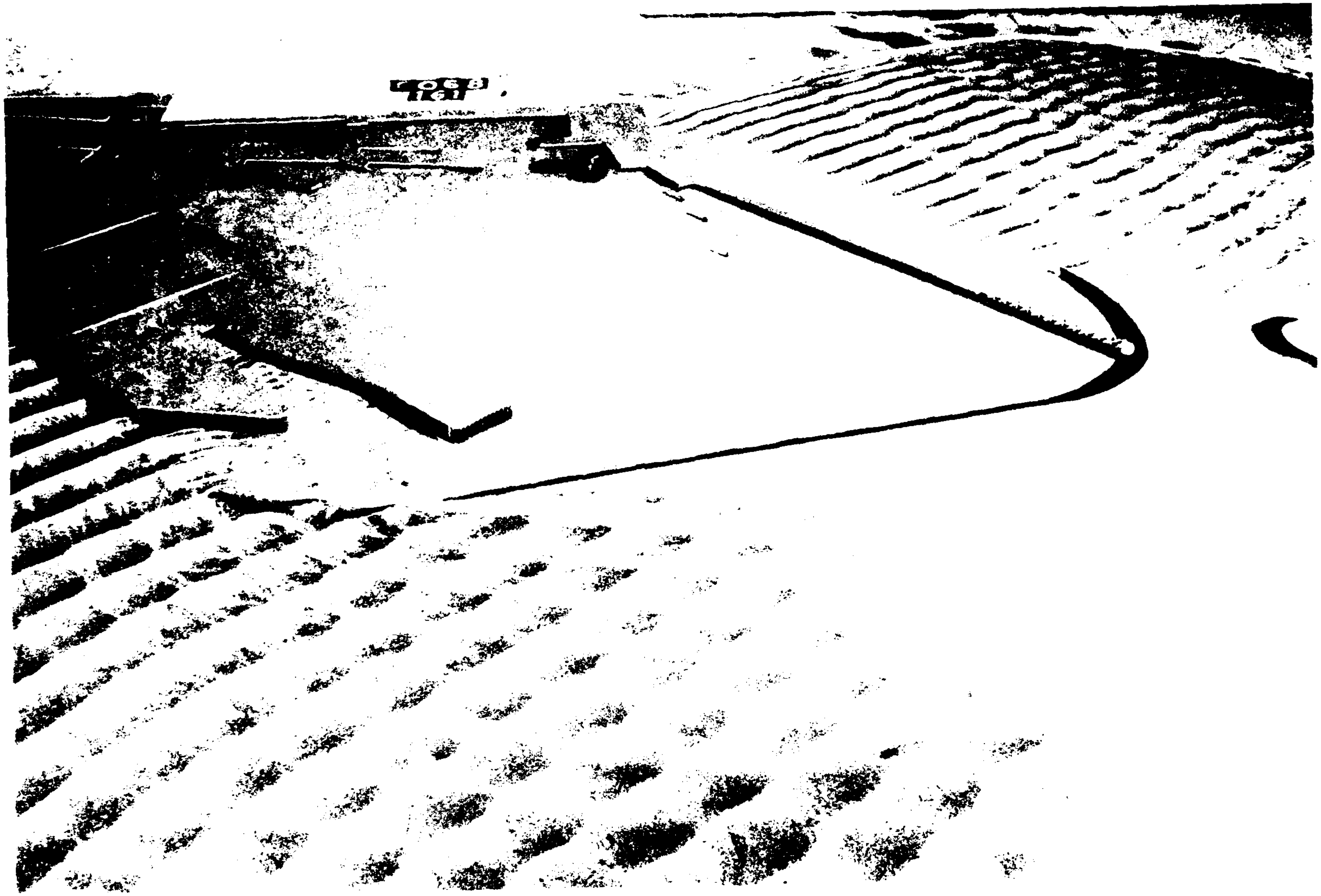

Photo 80 Typical wave patterns for Plan 38; 3.8-sec, 4.1-ft waves from northwest; +5.7 ft swl

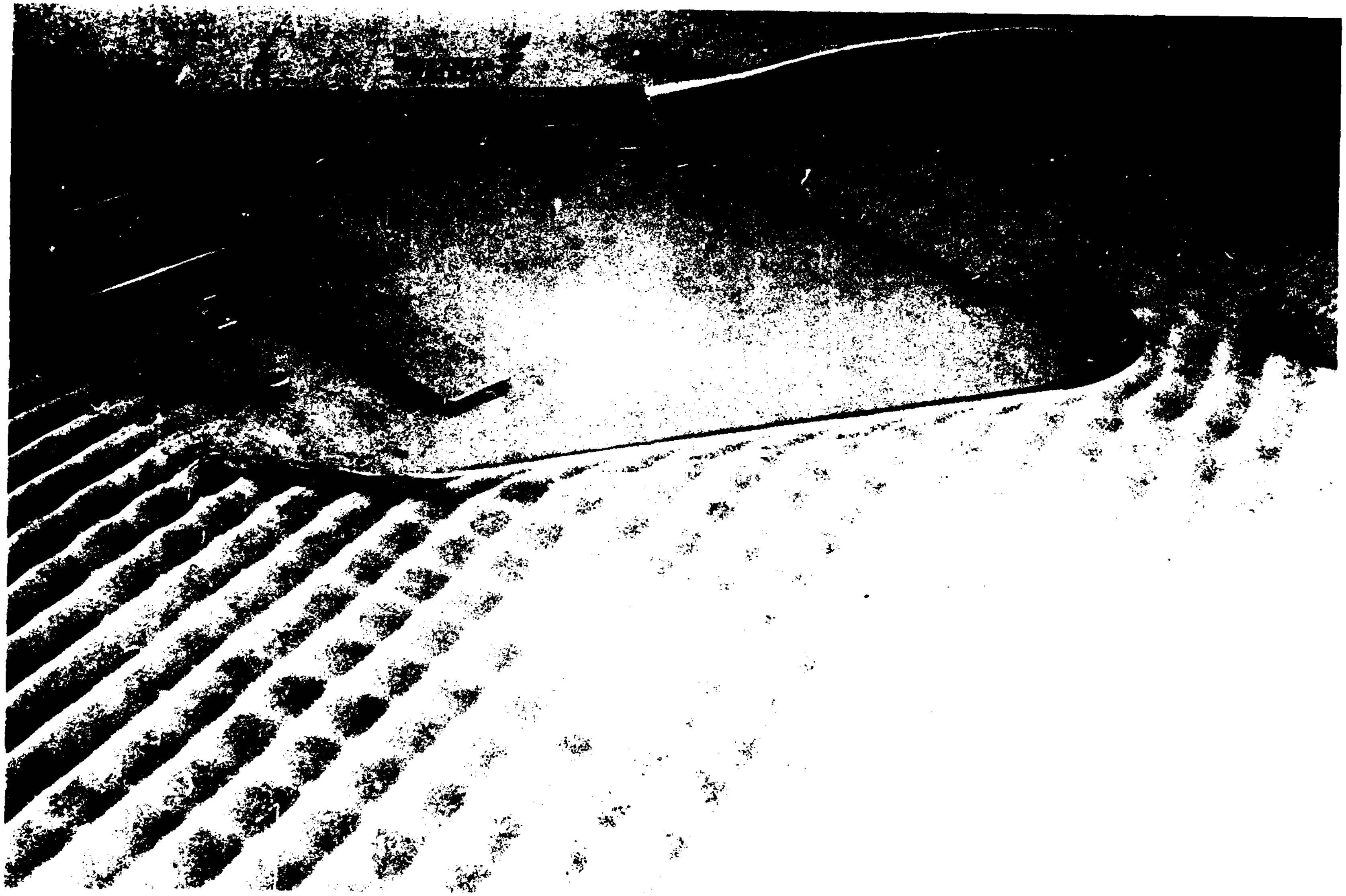

Photo 81. Typical wave patterns for Plan 38; 3.6-sec, 2-ft waves from west-northwest; +5.7 ft swl

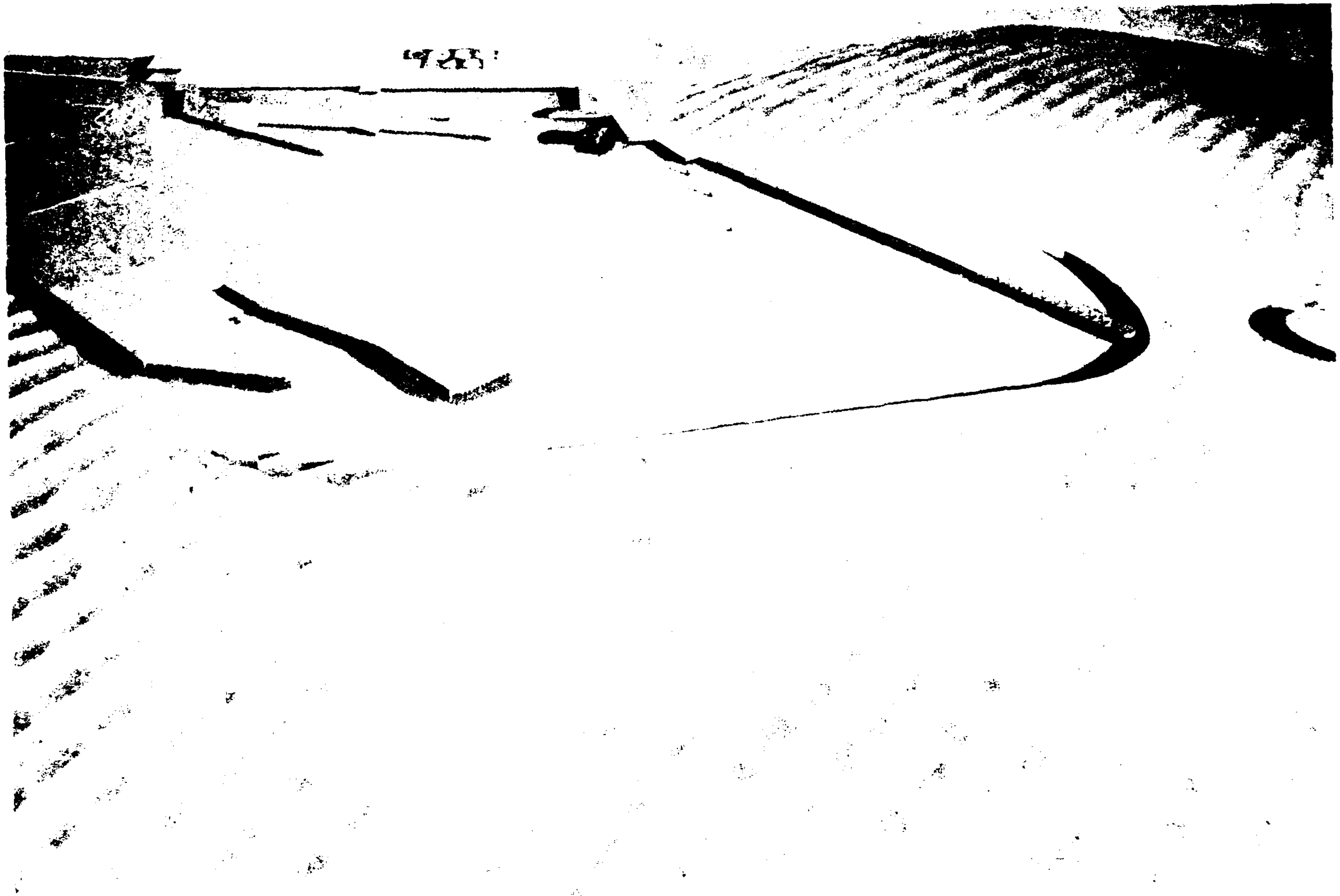

Photo 82. Typical wave patterns for Plan 38; 3.6-sec, 3.4-ft waves from west-northwest; +5.7 ft swl

Photo 83. Typical wave patterns for Plan 38; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

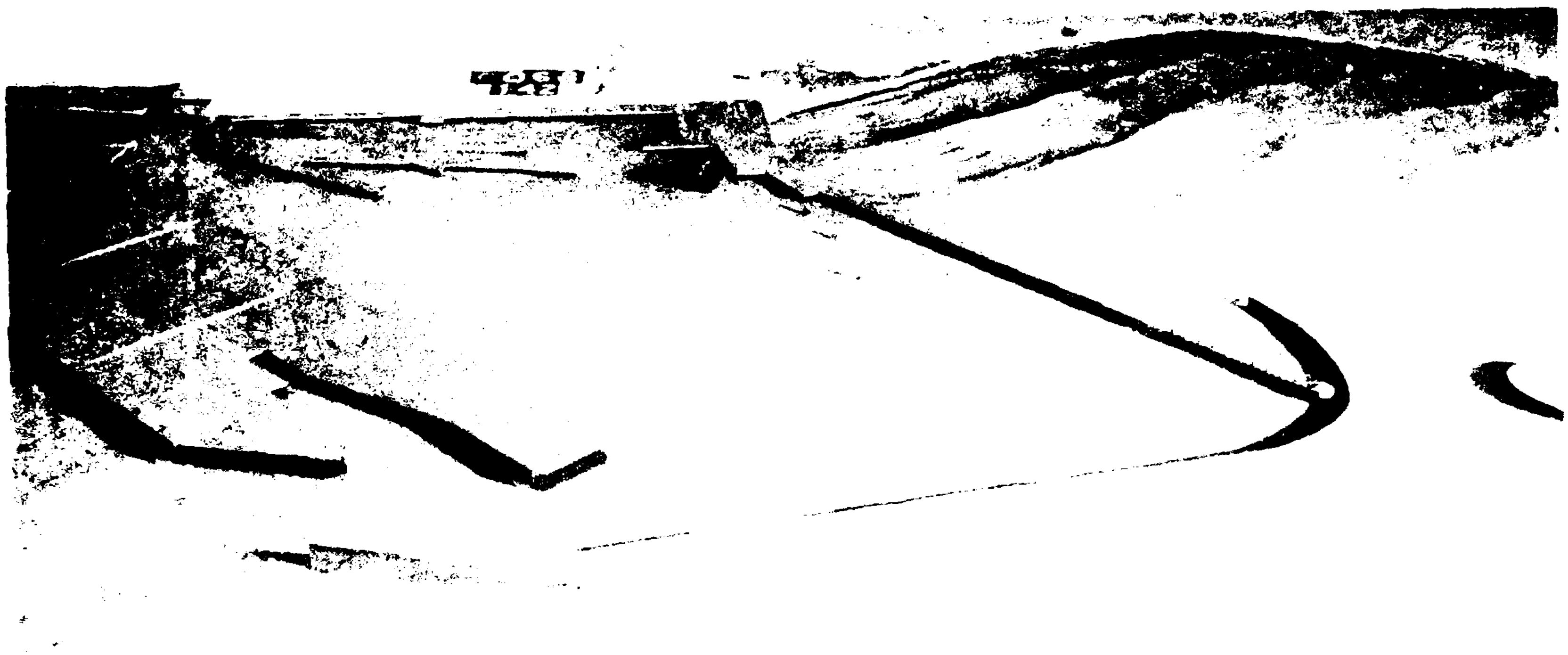

Photo 84. Typical wave patterns for Plan 38; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

Photo 85. Typical wave patterns for Plan 40; 10-sec, 2.5-ft waves from west-northwest; +5.7 ft swl

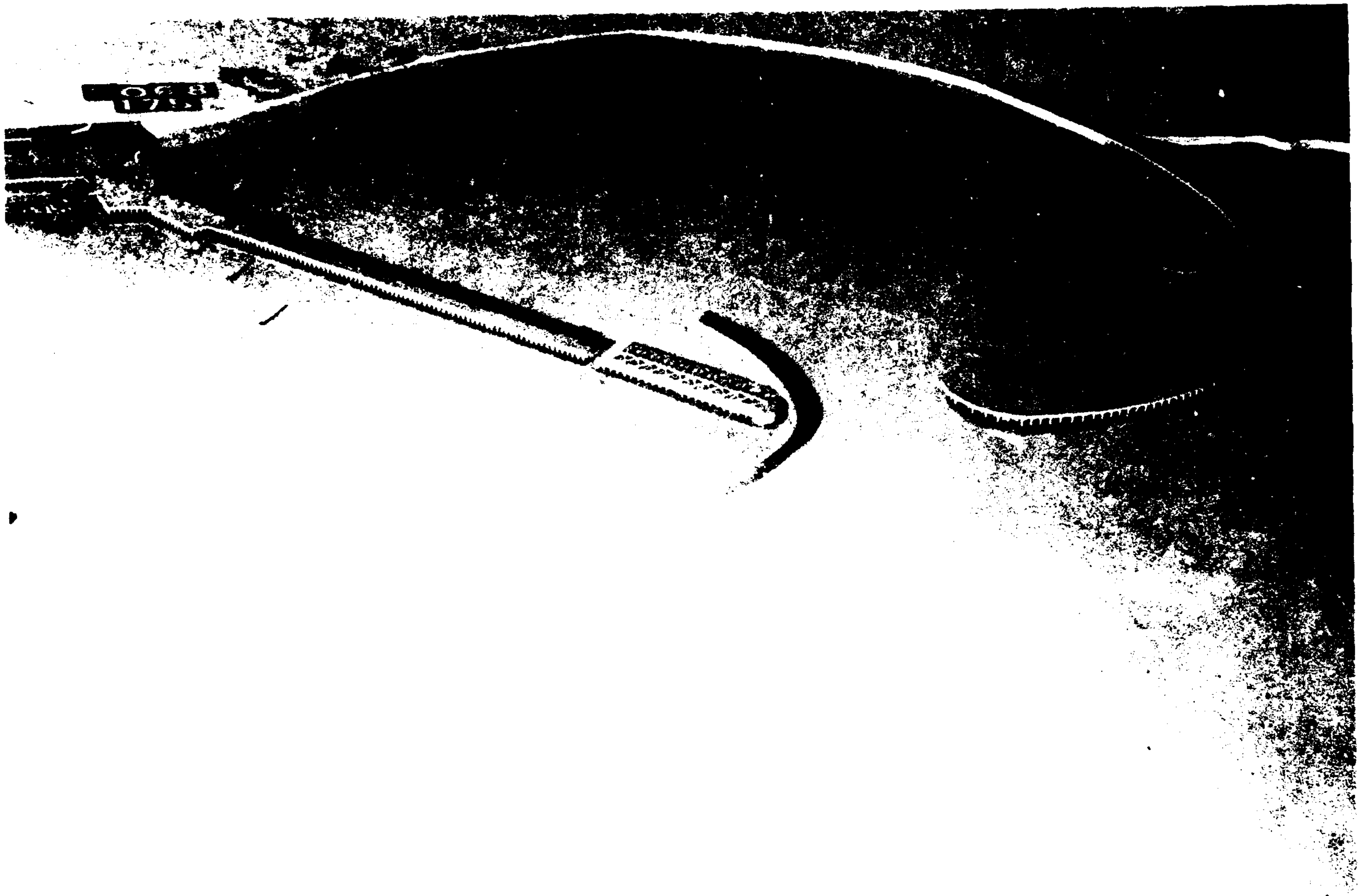

Photo 86. General movement of tracer material for Plan 38; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

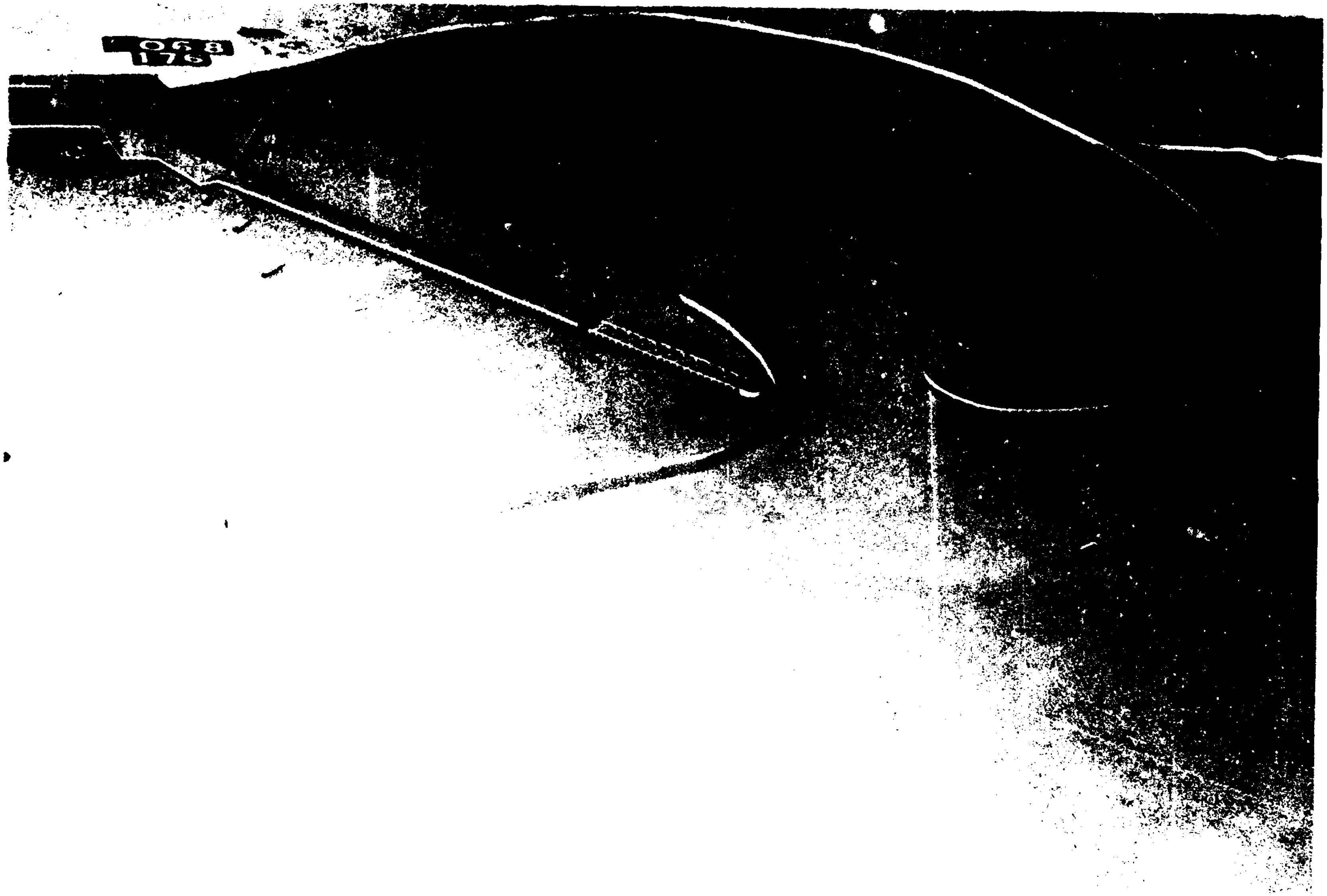

Photo 87. General movement of tracer material for Plan 38; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

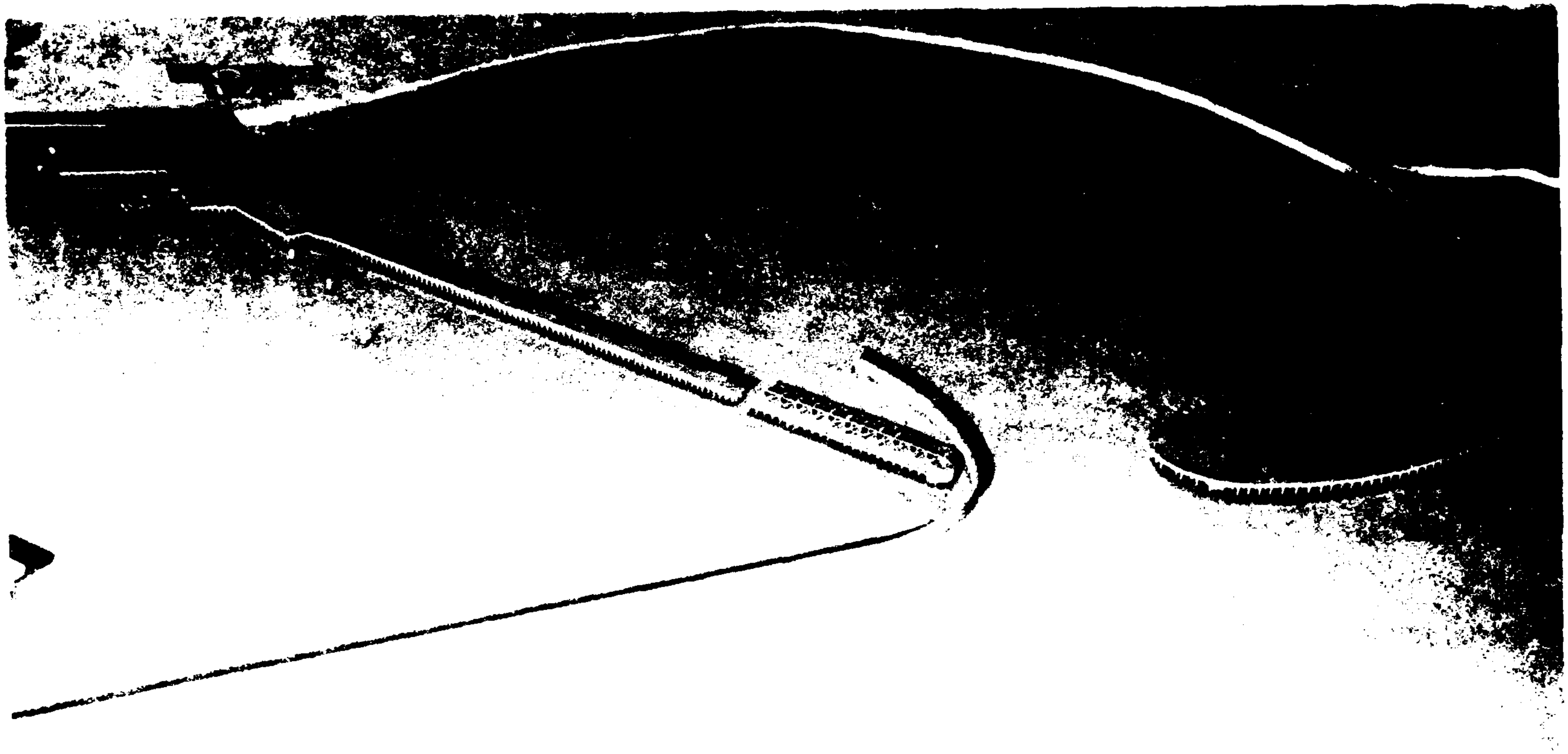

Photo 88. General movement of tracer material for Plan 38; 4.2-sec, 4.8-ft waves from north-northeast; 0.0-ft swl

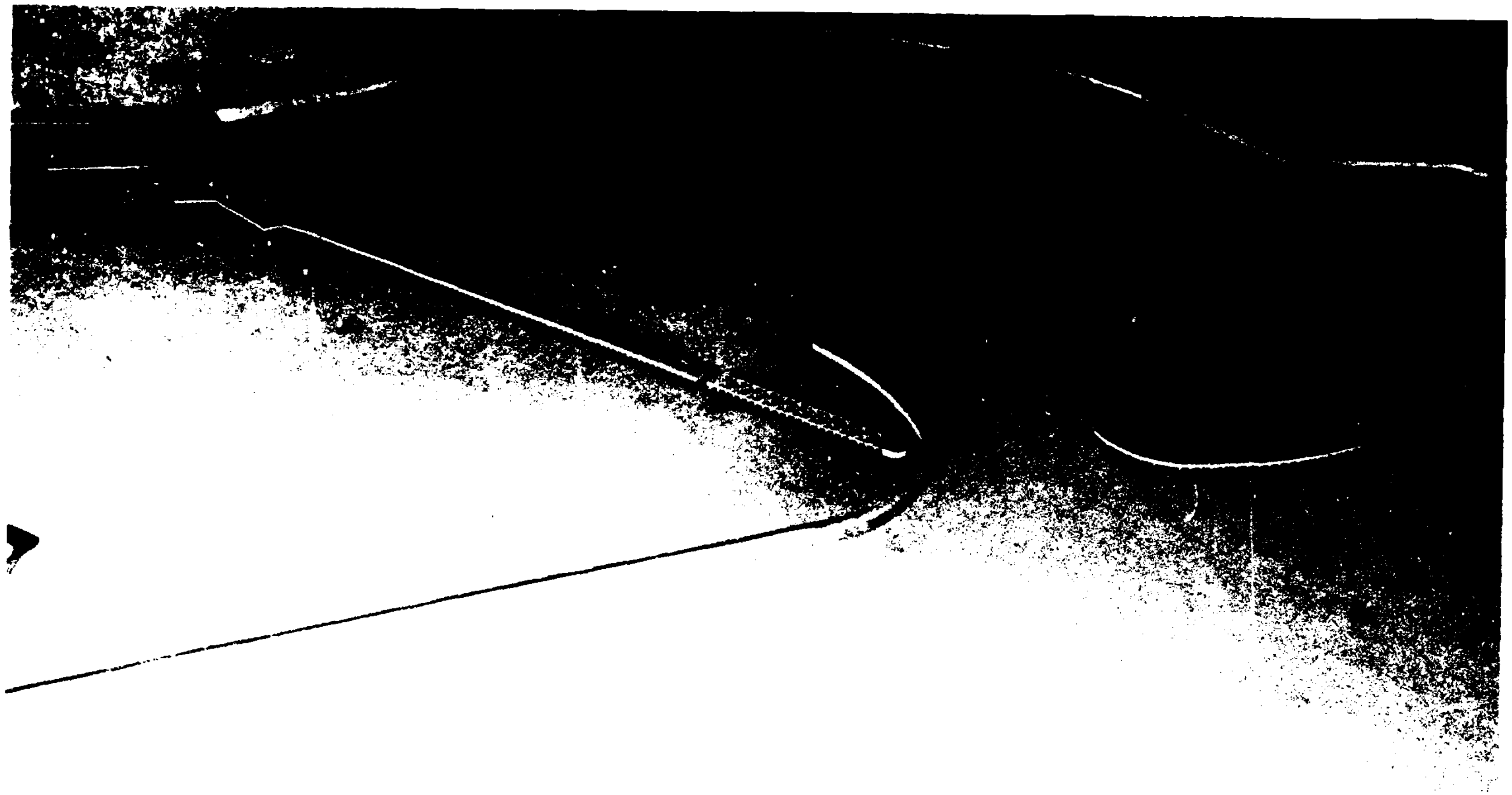

Photo 89. General movement of tracer material for Plan 38; 4.2-sec, 4.8-ft waves from north-northeast; +5.7 ft swl

Photo 90. General movement of tracer material for Plan 38; 3.6-sec, 3.1-ft waves from north; 0.0-ft swl

Photo 91. General movement of tracer material for Plan 38; 3.6-sec, 3.1-ft waves from north; +5.7 ft swl

Photo 92. General movement of tracer material for Plan 38; 3.6-sec, 3.3-ft waves from north-northwest; 0.0-ft swl

Photo 93. General movement of tracer material for Plan 38; 3.6-sec, 3.3-ft waves from north-northwest; +5.7 ft swl

Photo 94. General movement of tracer material for Plan 38; 3.8-sec, 4.1-ft waves from northwest; 0.0-ft swl

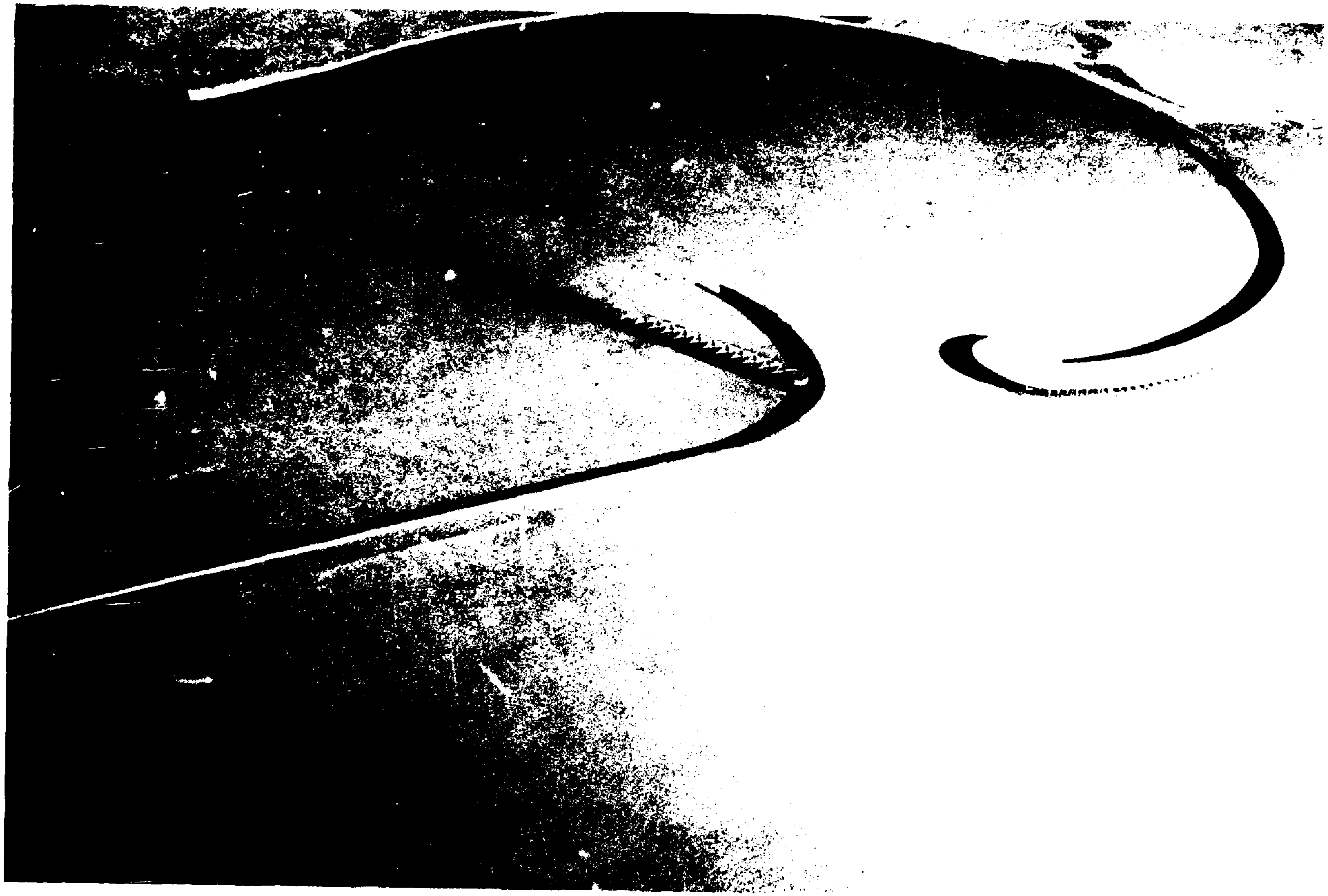

Photo 95. General movement of tracer material for Plan 38; 3.8-sec, 4.1-ft waves from northwest; +5.7 ft swl

Photo 96. General movement of tracer material for Plan 38; 3.6-sec, 3.4-ft waves from west-northwest; 0.0-ft swl

Photo 97. General movement of tracer material for Plan 38; 3.6-sec, 3.4-ft waves from west-northwest; +5.7 ft swl

Photo 98. General movement of tracer material for Plan 38; 10-sec, 2-ft waves from west-northwest; 0.0-ft swl

Photo 99. General movement of tracer material for Plan 38; 10-sec, 2-ft waves from west-northwest; +5.7 ft swl

Photo 100. General movement of tracer material for Plan 38; 10-sec, 3-ft waves from west-northwest; 0.0-ft swl

Photo 101. General movement of tracer material for Plan 38; 10-sec, 3-ft waves from west-northwest; +5.7 ft swl

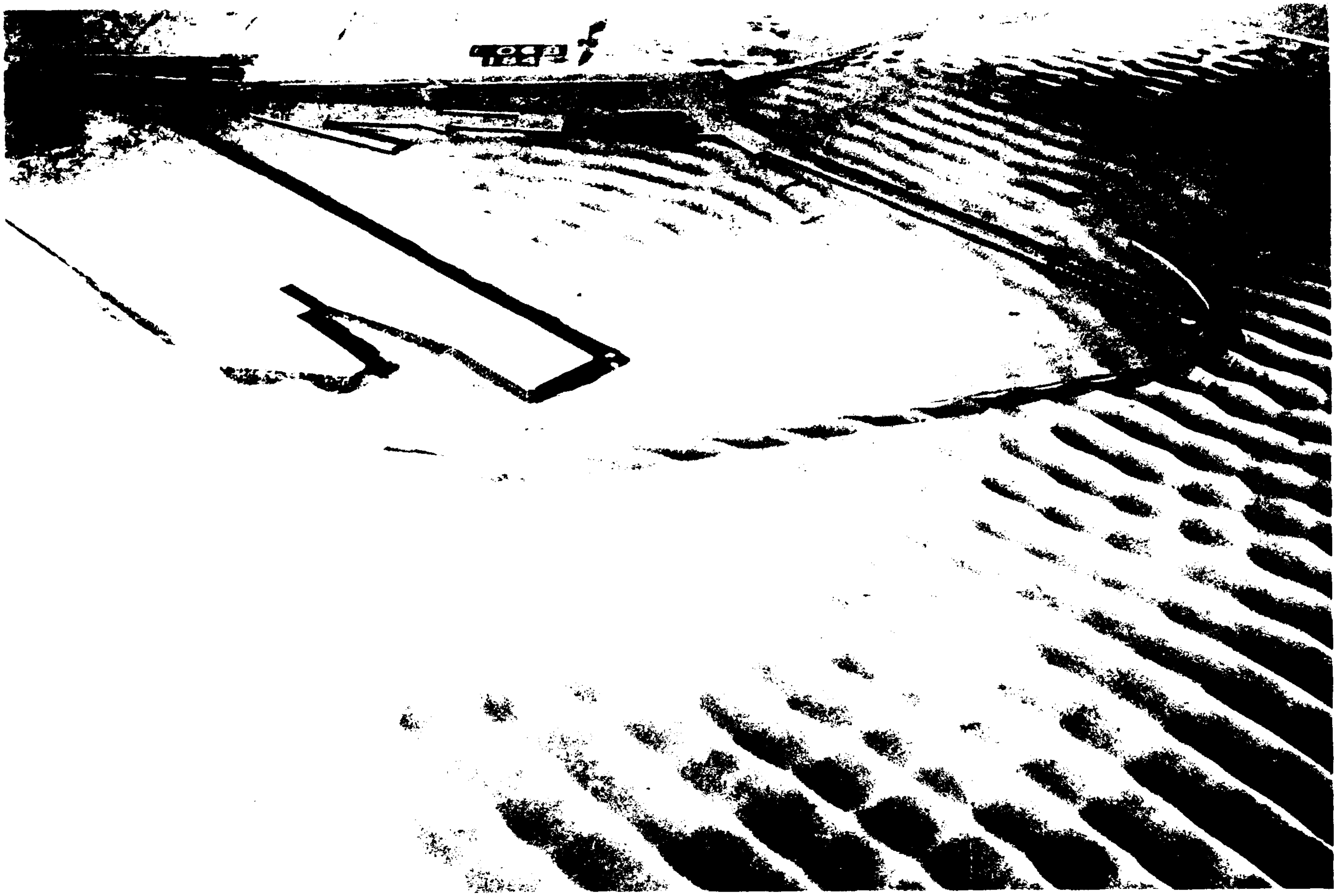

Photo 102. Typical wave patterns for Plan 41; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

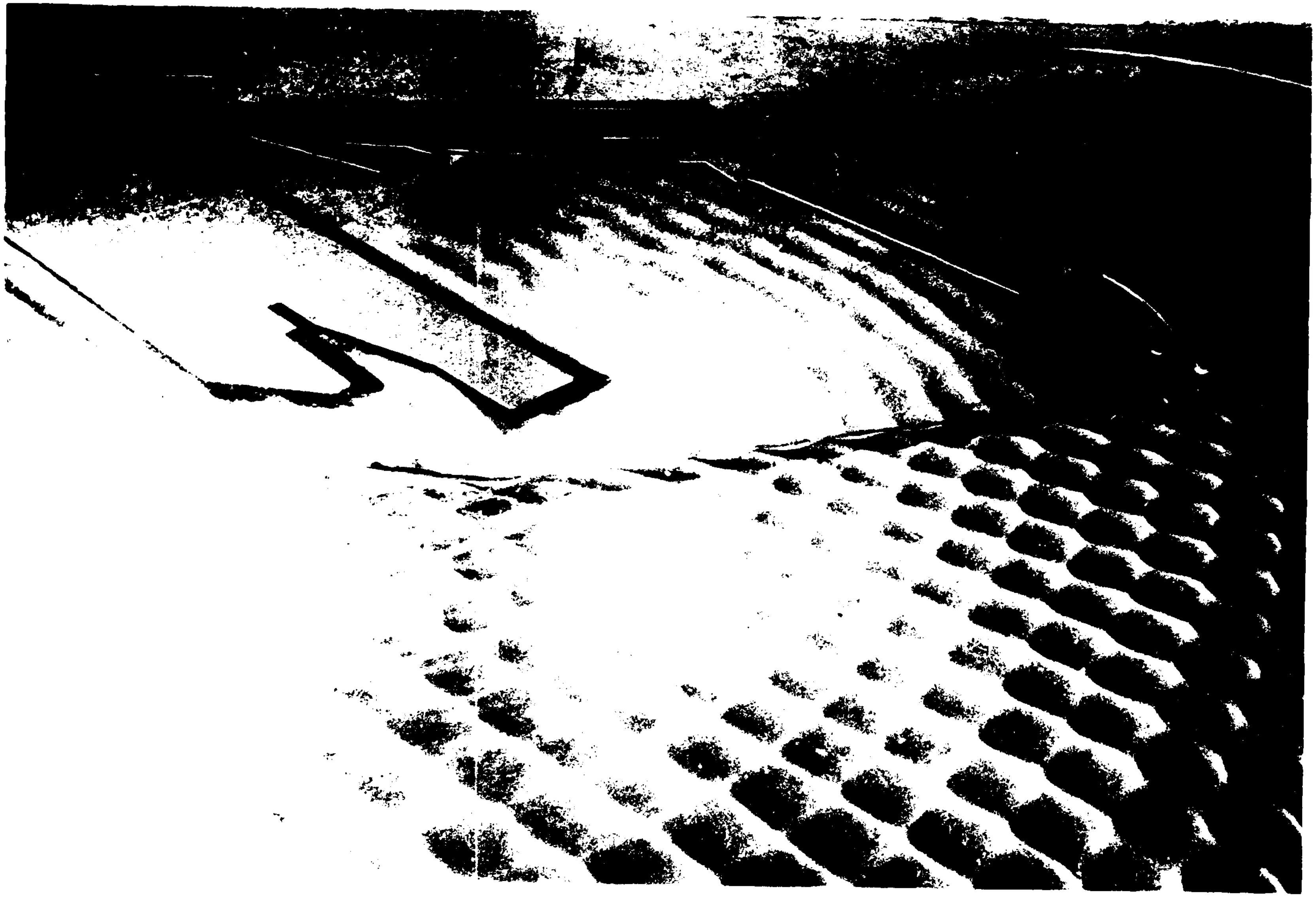

Photo 103. Typical wave patterns for Plan 42; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

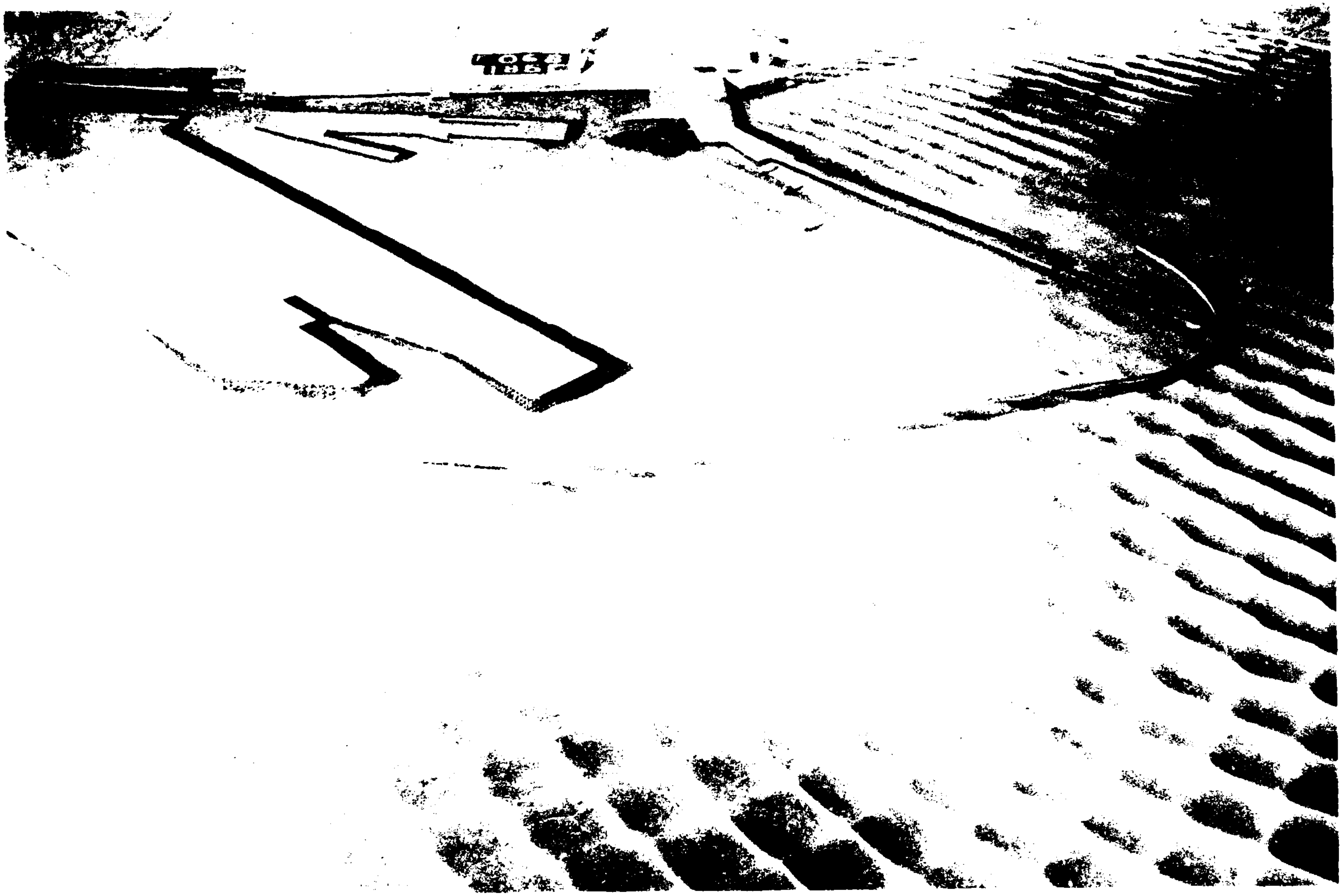

Photo 104. Typical wave patterns for Plan 43; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

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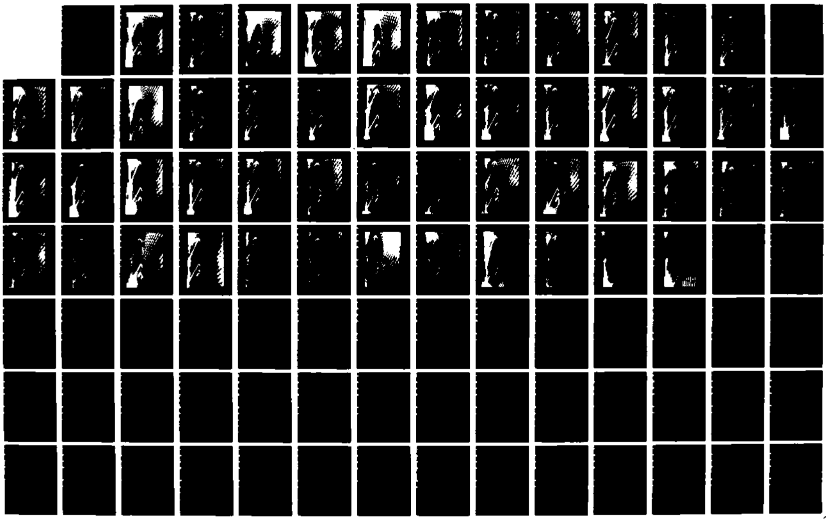

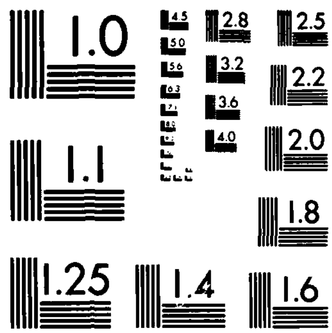

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Photo 105. Typical wave patterns for Plan 44; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

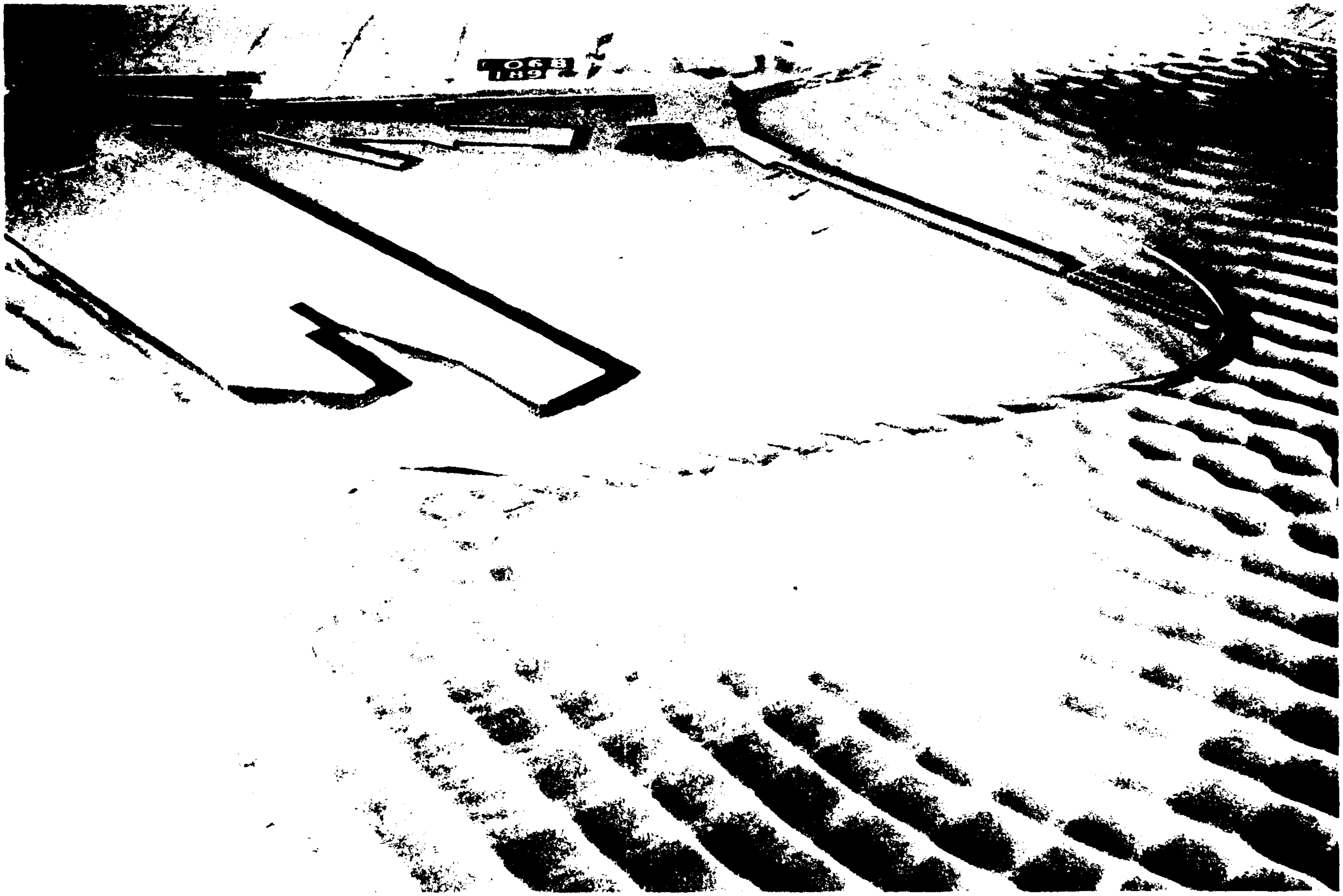


Photo 106. Typical wave patterns for Plan 45; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

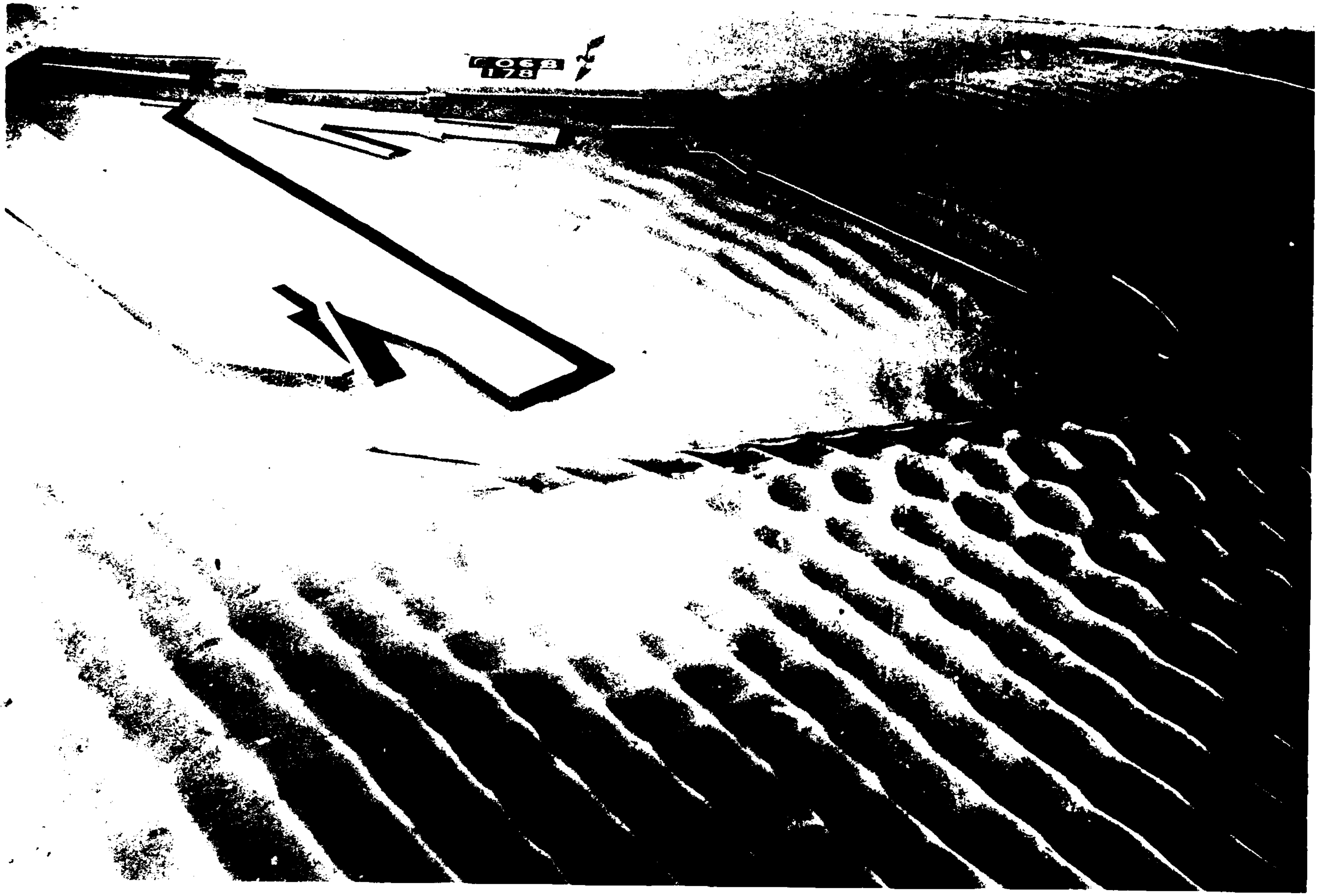


Photo 107. Typical wave patterns for Plan 46; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

Photo 108. Typical wave patterns for Plan 48; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

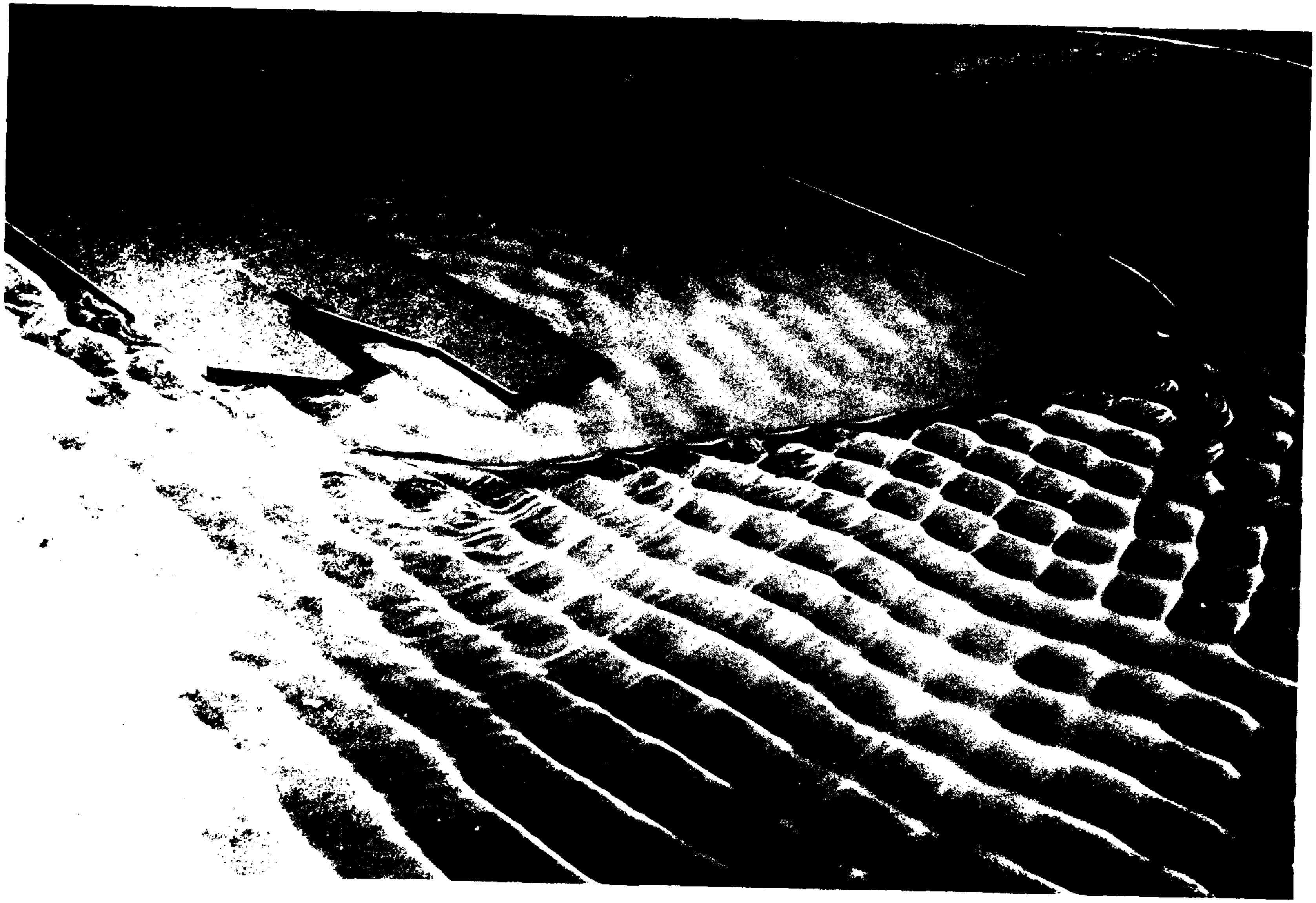


Photo 109. Typical wave patterns for Plan 49; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

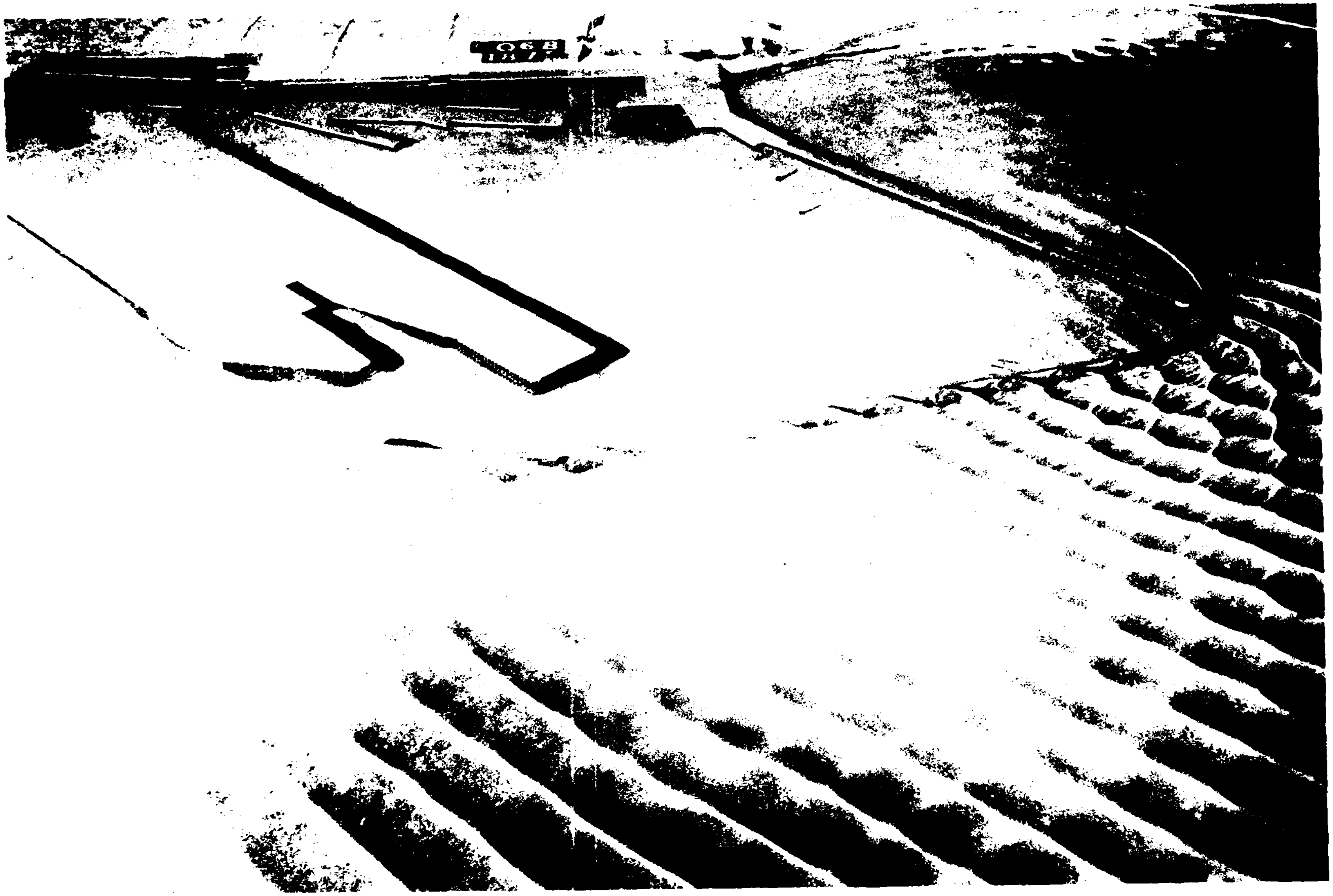


Photo 110. Typical wave patterns for Plan 50; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

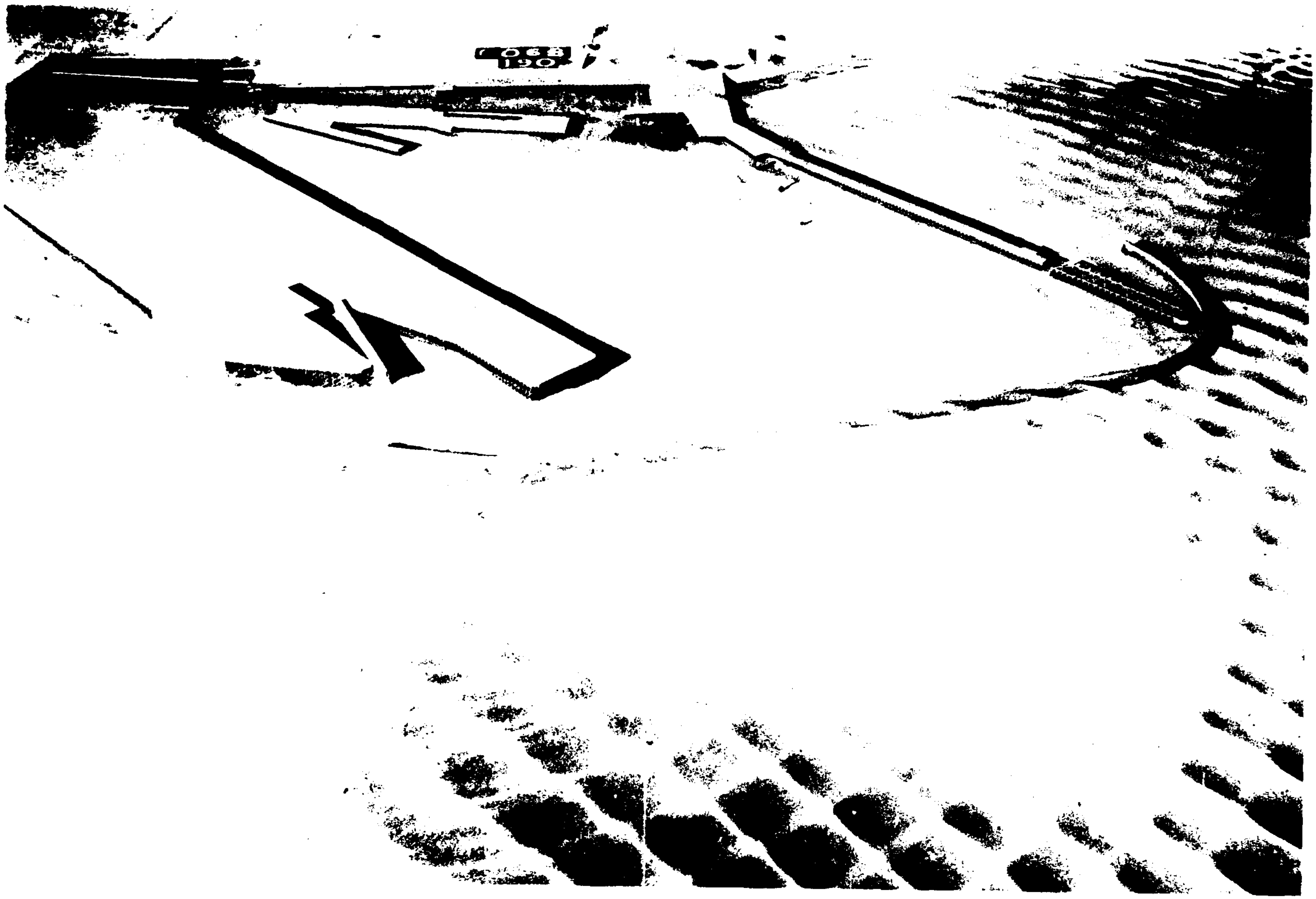


Photo 111. Typical wave patterns for Plan 51; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

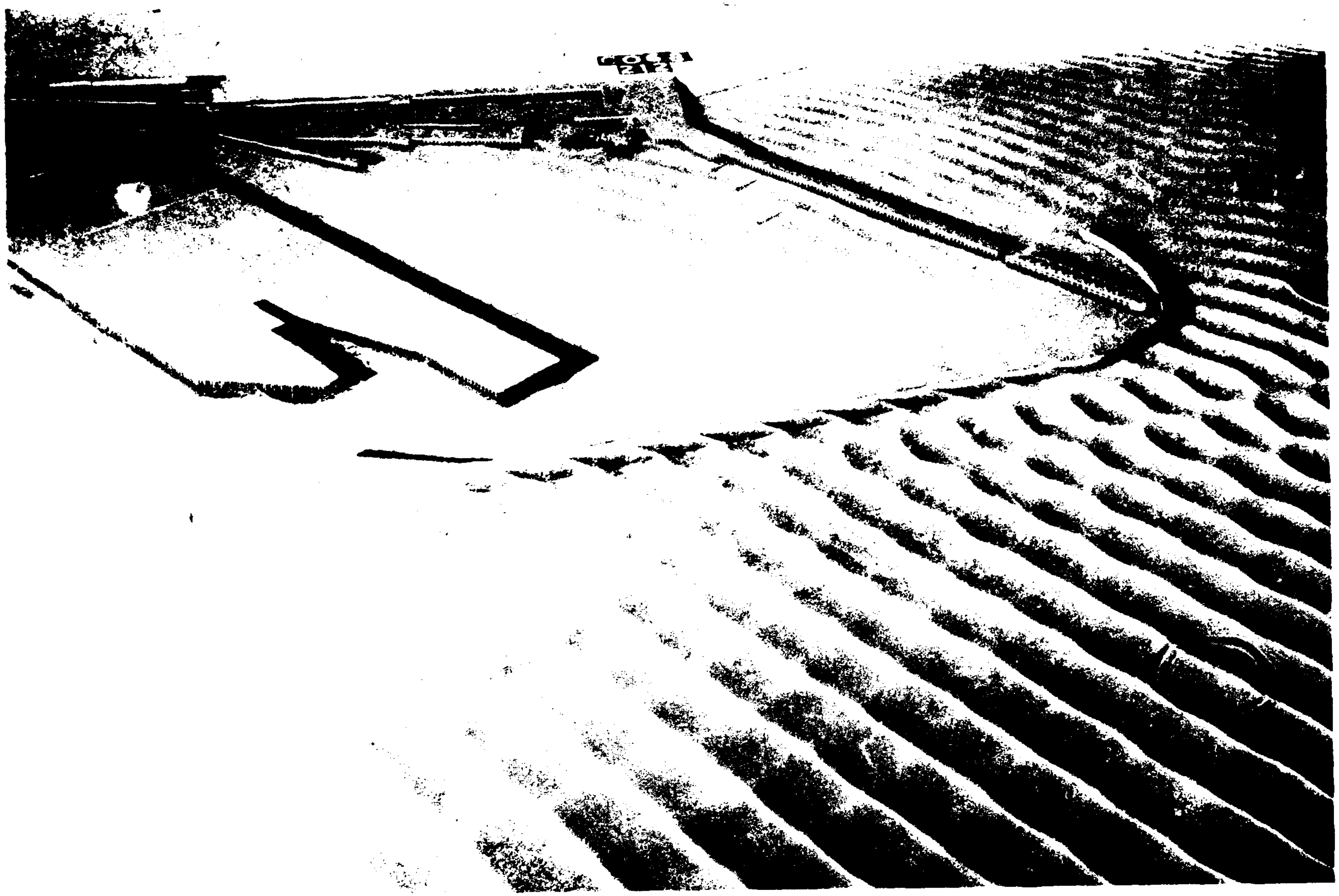


Photo 112. Typical wave patterns for Plan 52; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

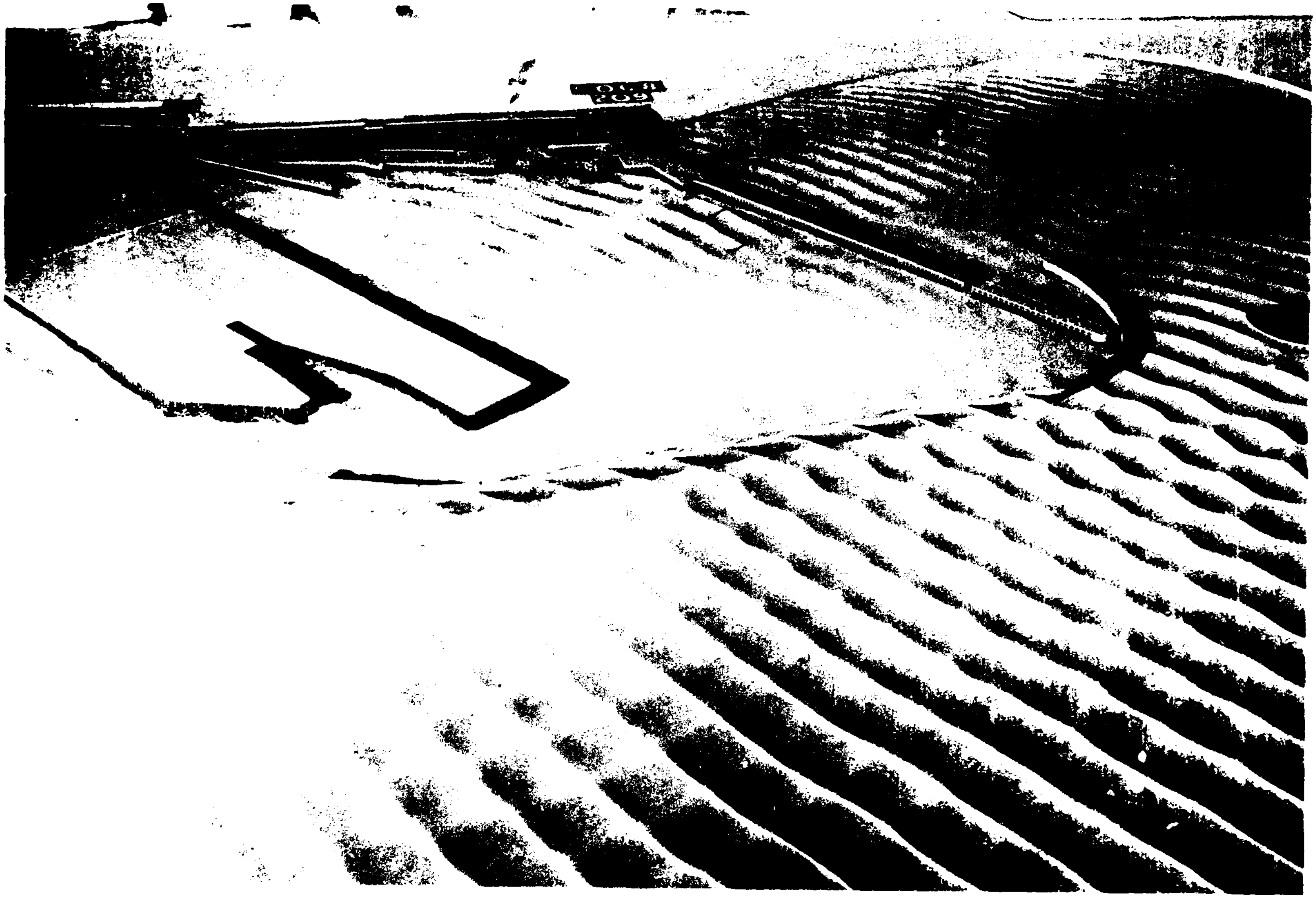


Photo 113. Typical wave patterns for Plan 53; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

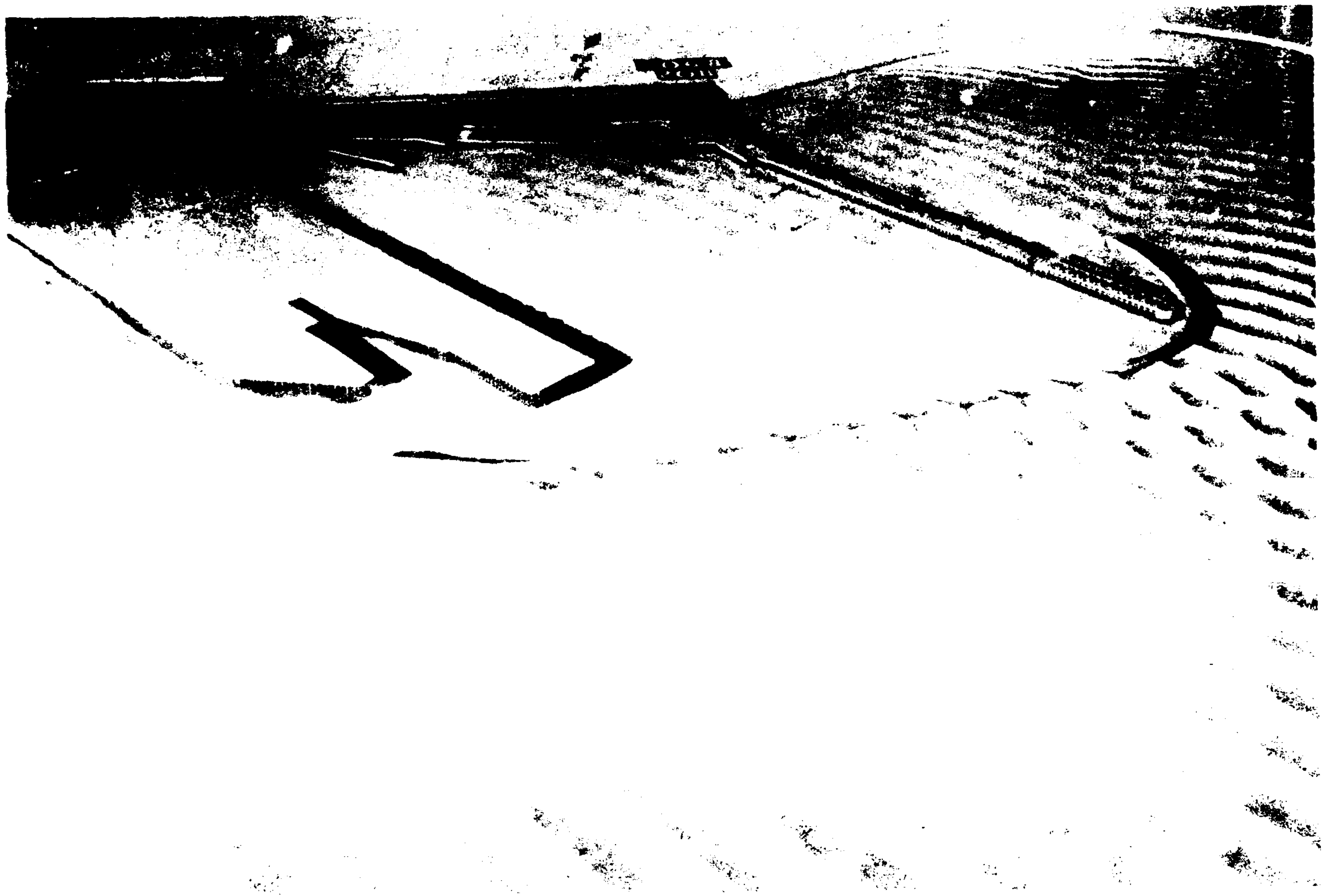


Photo 114. Typical wave patterns for Plan 54; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

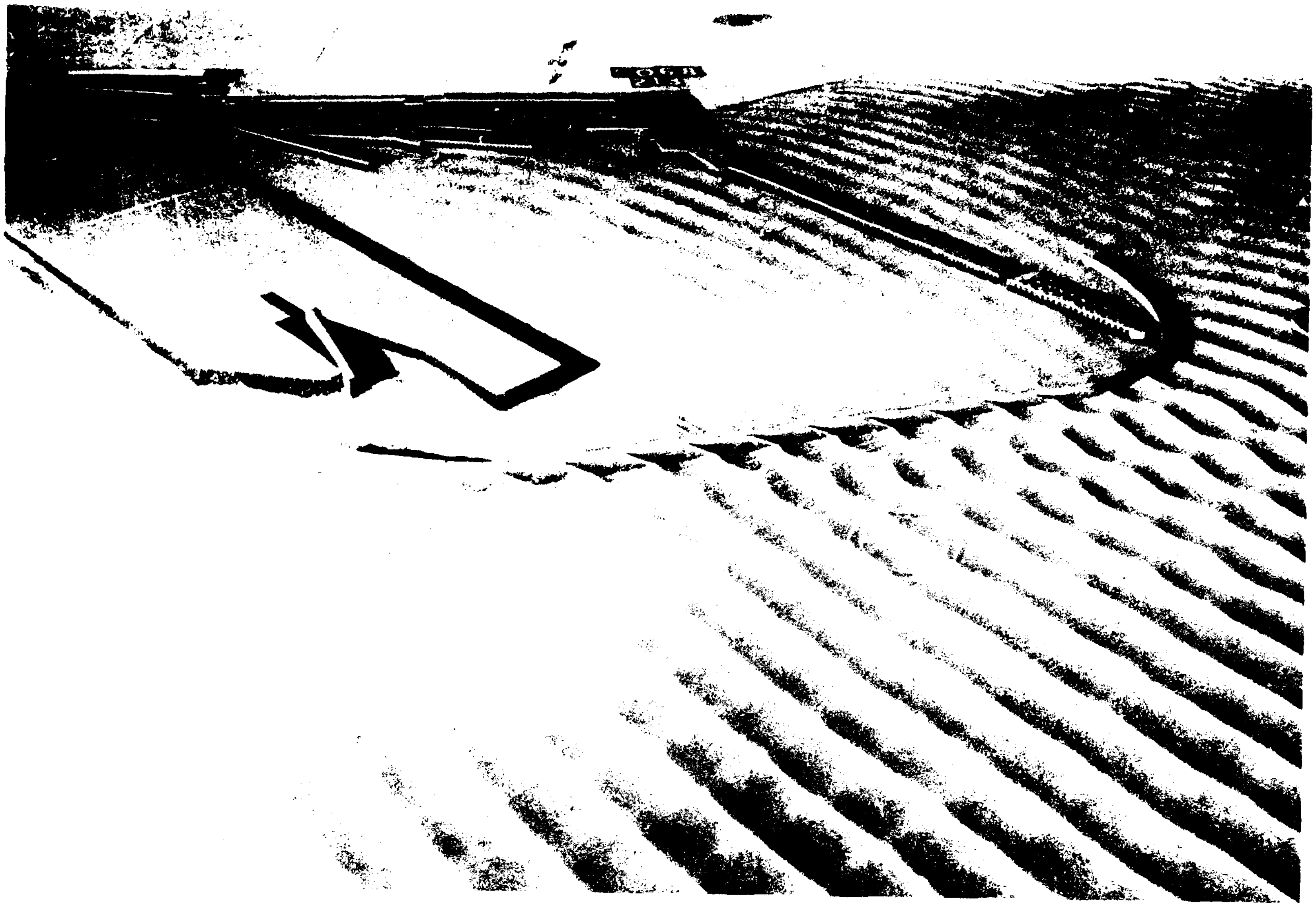


Photo 115. Typical wave patterns for Plan 55; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

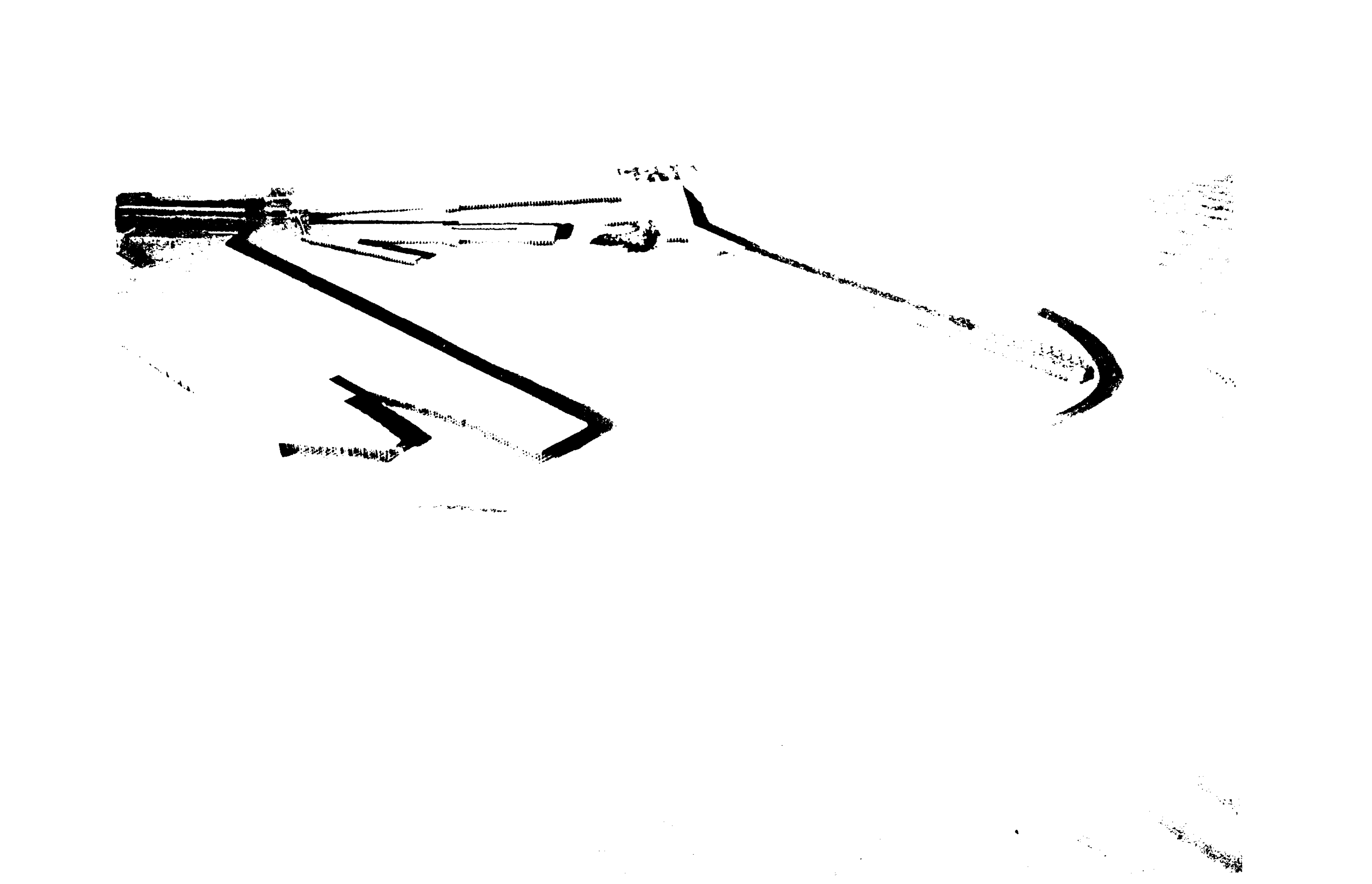


Photo 116. Typical wave patterns for Plan 56; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

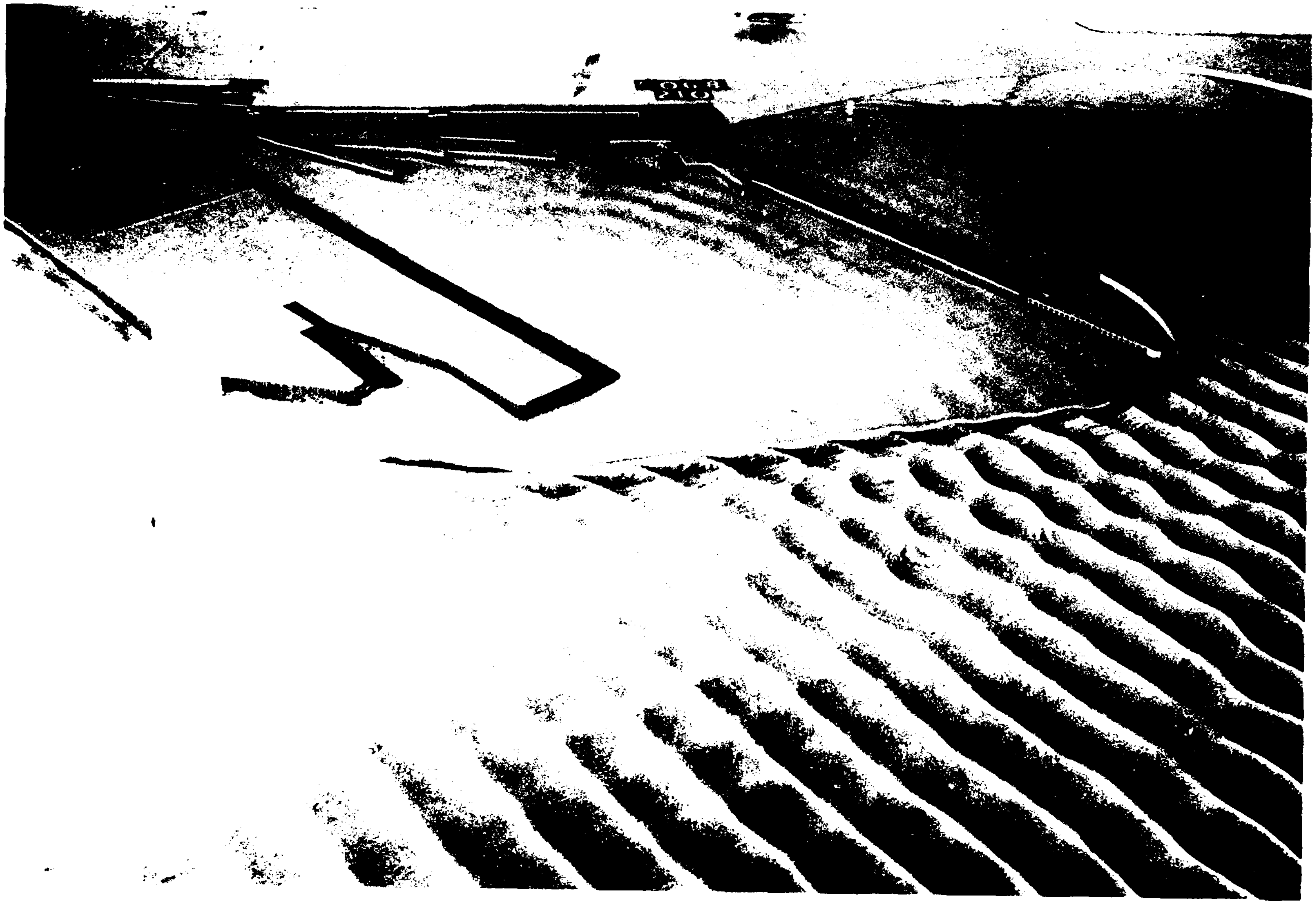


Photo 117. Typical wave patterns for Plan 57; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

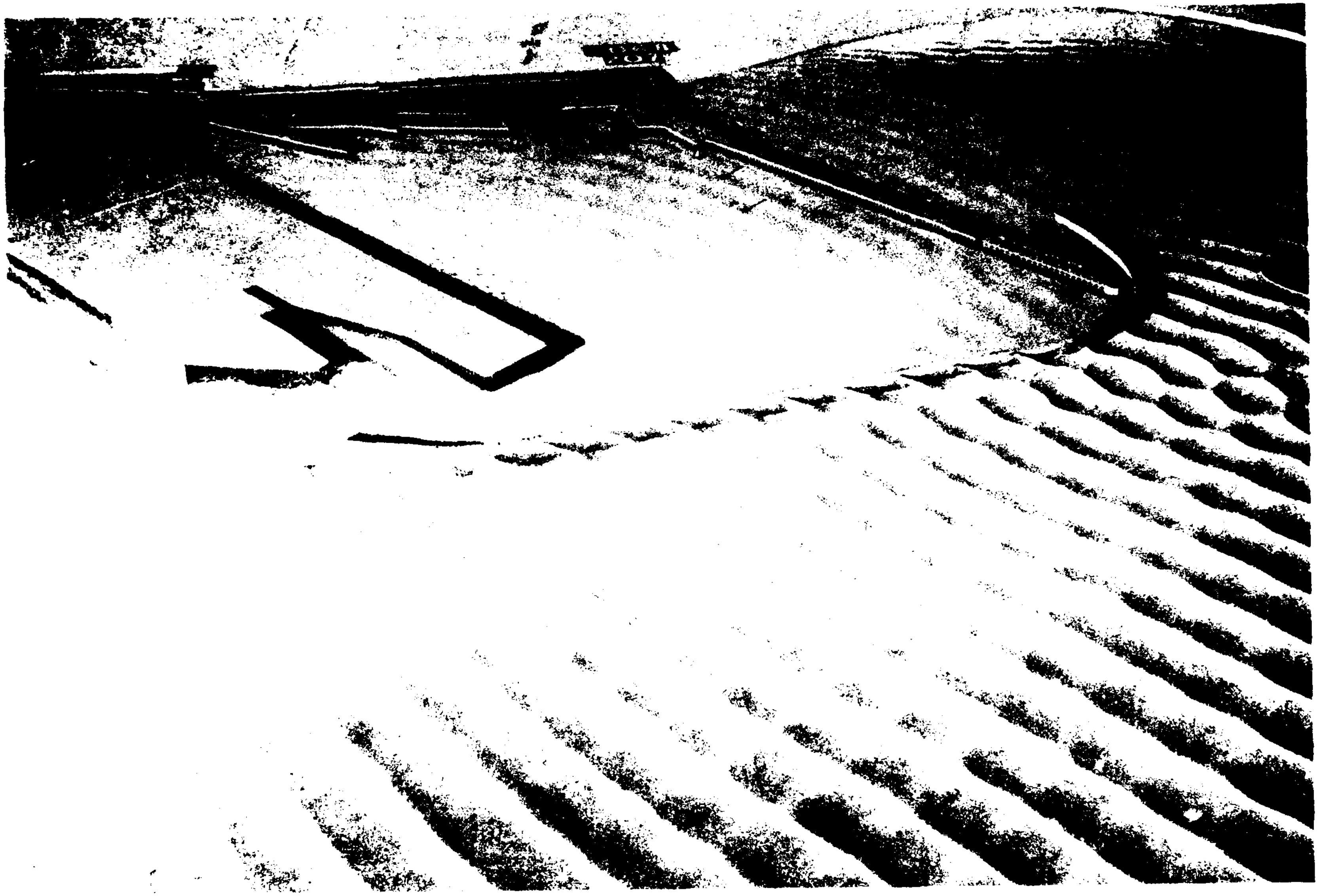


Photo 118. Typical wave patterns for Plan 58; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

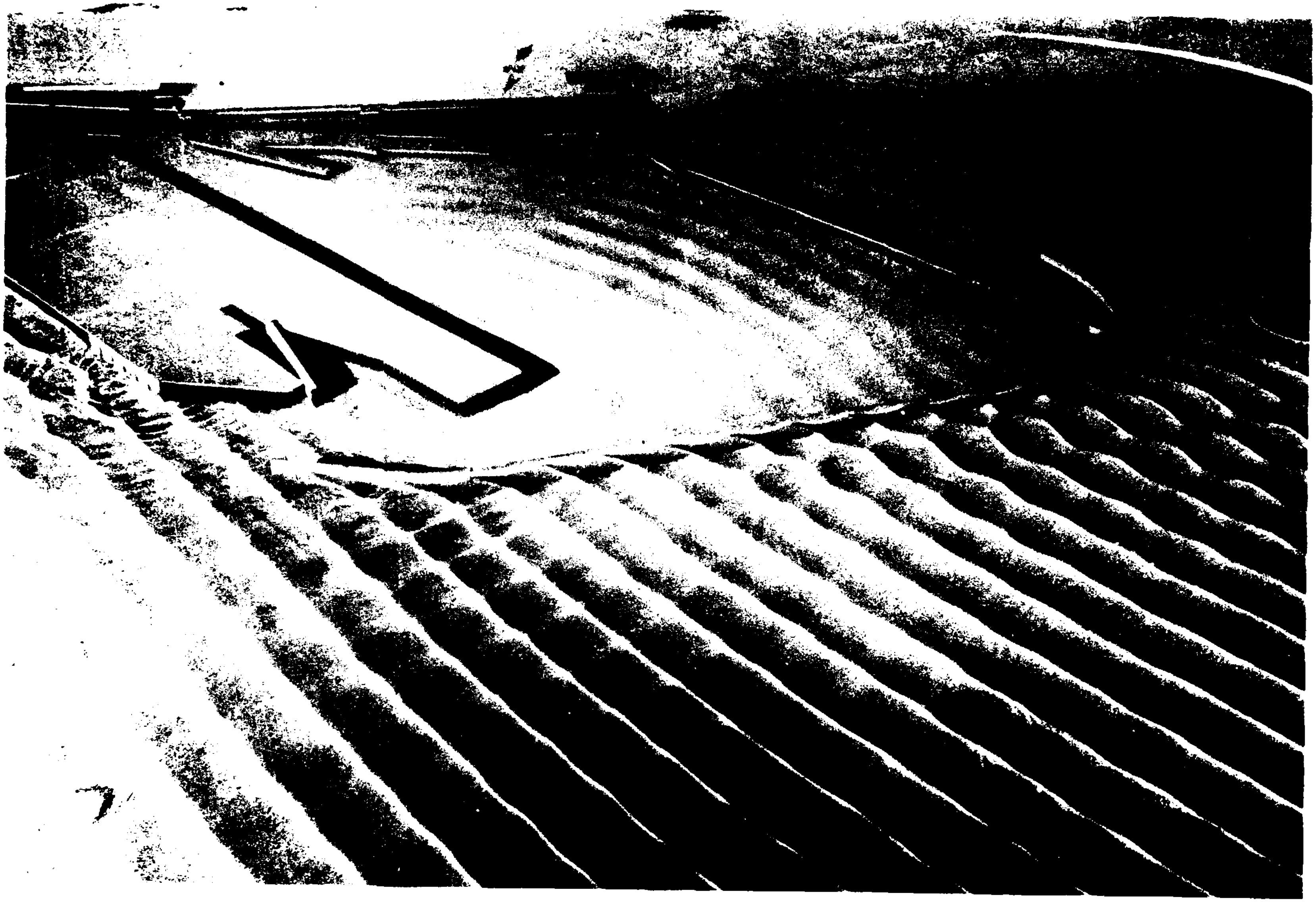


Photo 119. Typical wave patterns for Plan 59; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

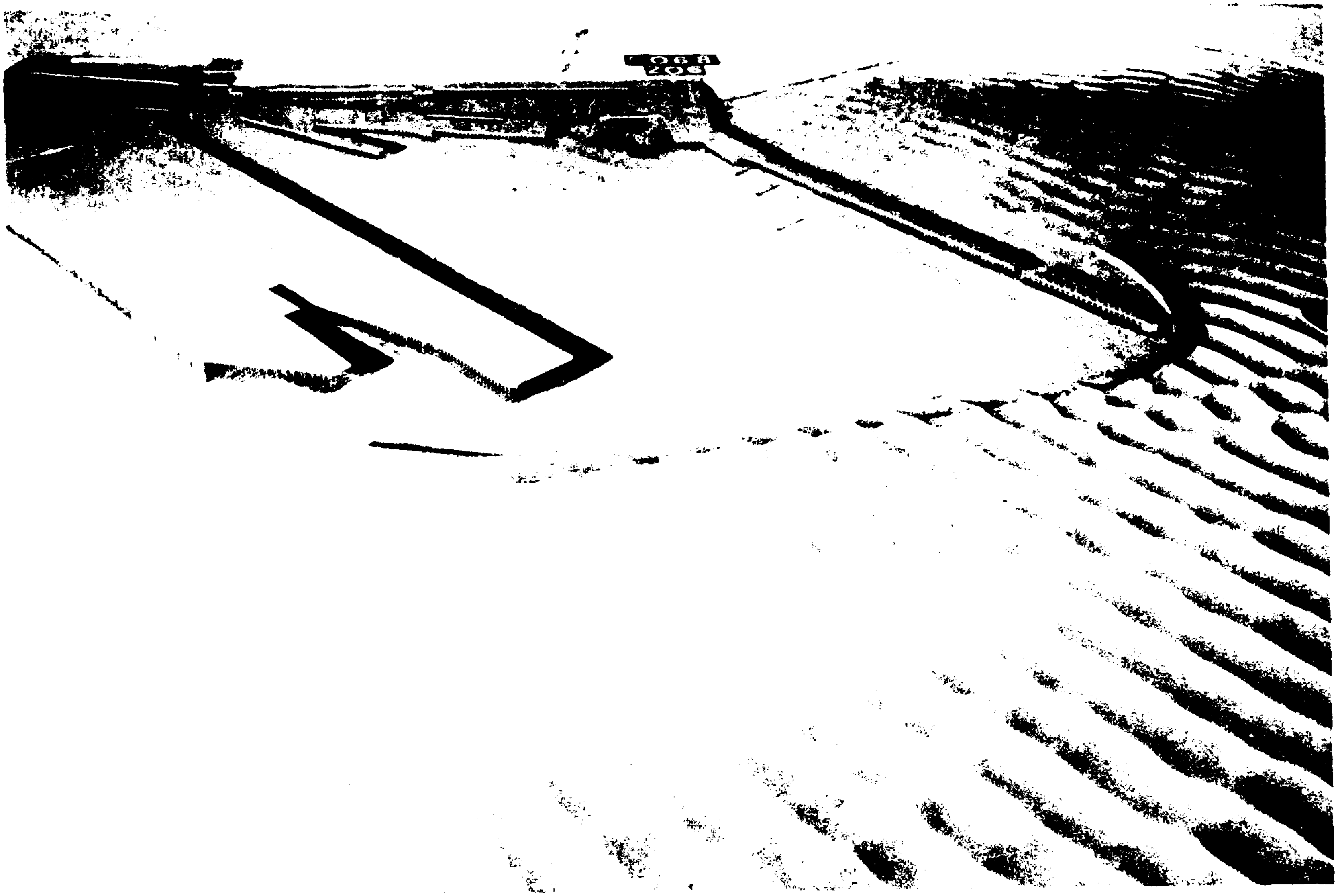


Photo 120. Typical wave patterns for Plan 60; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

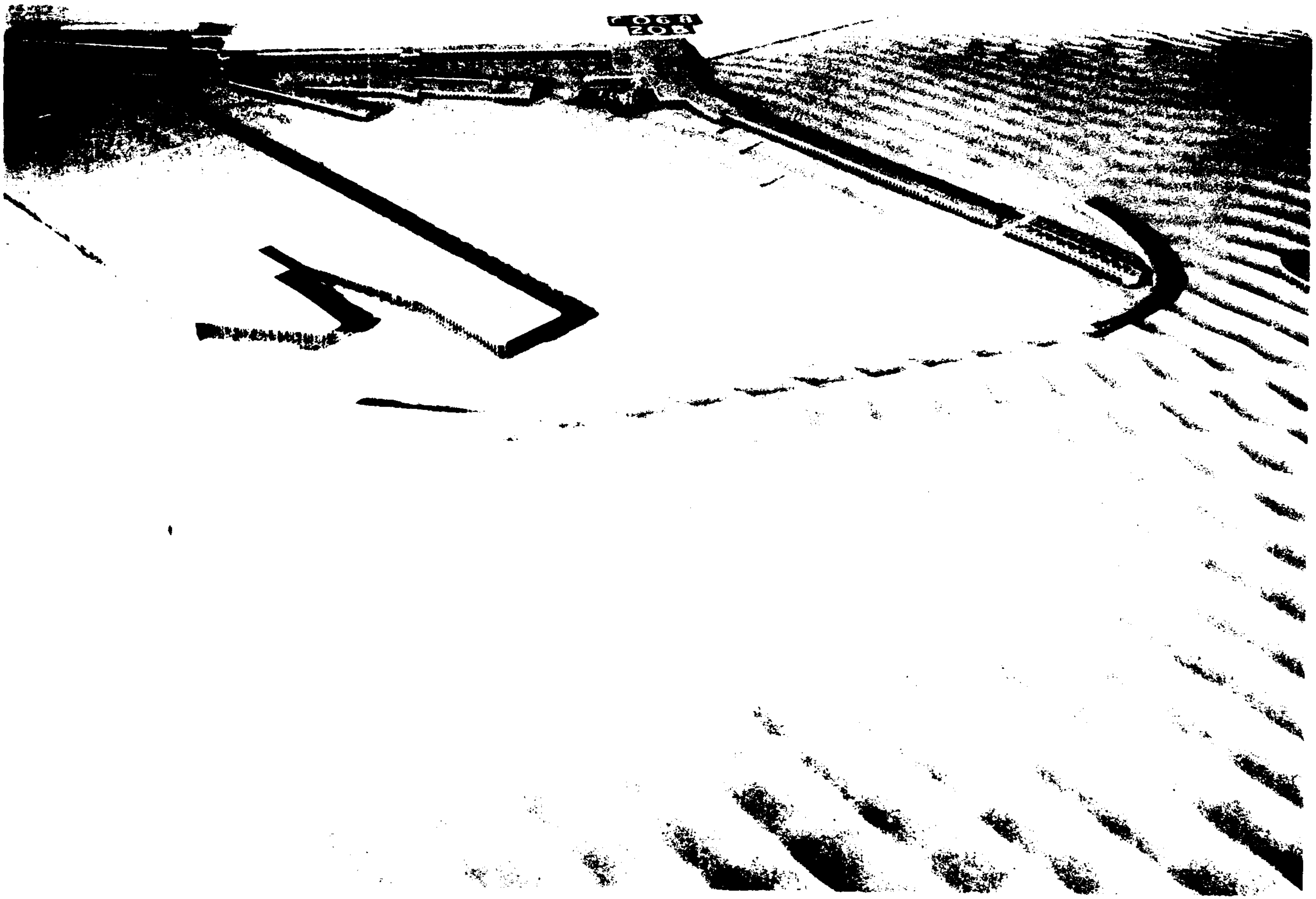


Photo 121. Typical wave patterns for Plan 61; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

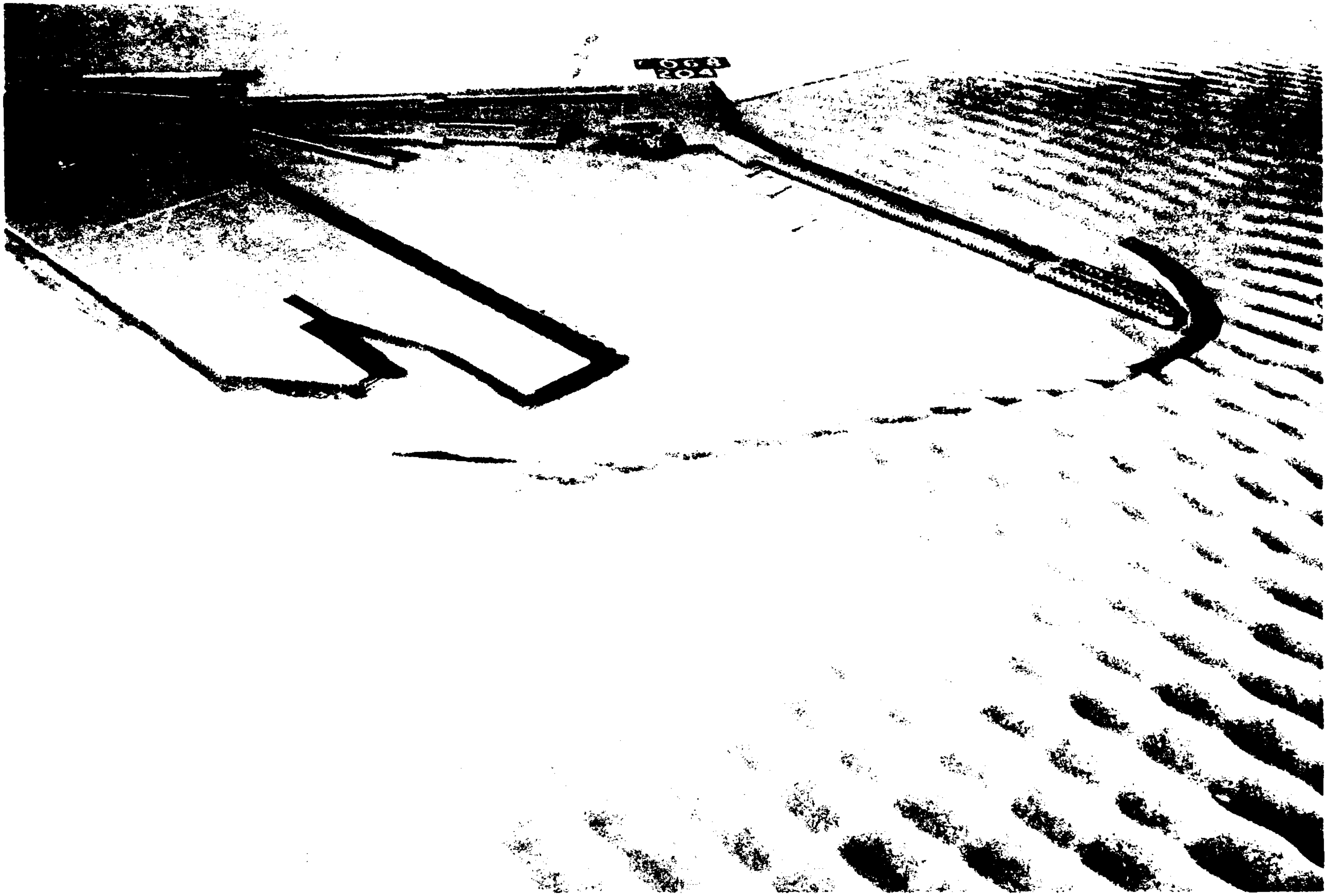


Photo 122. Typical wave patterns for Plan 62; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

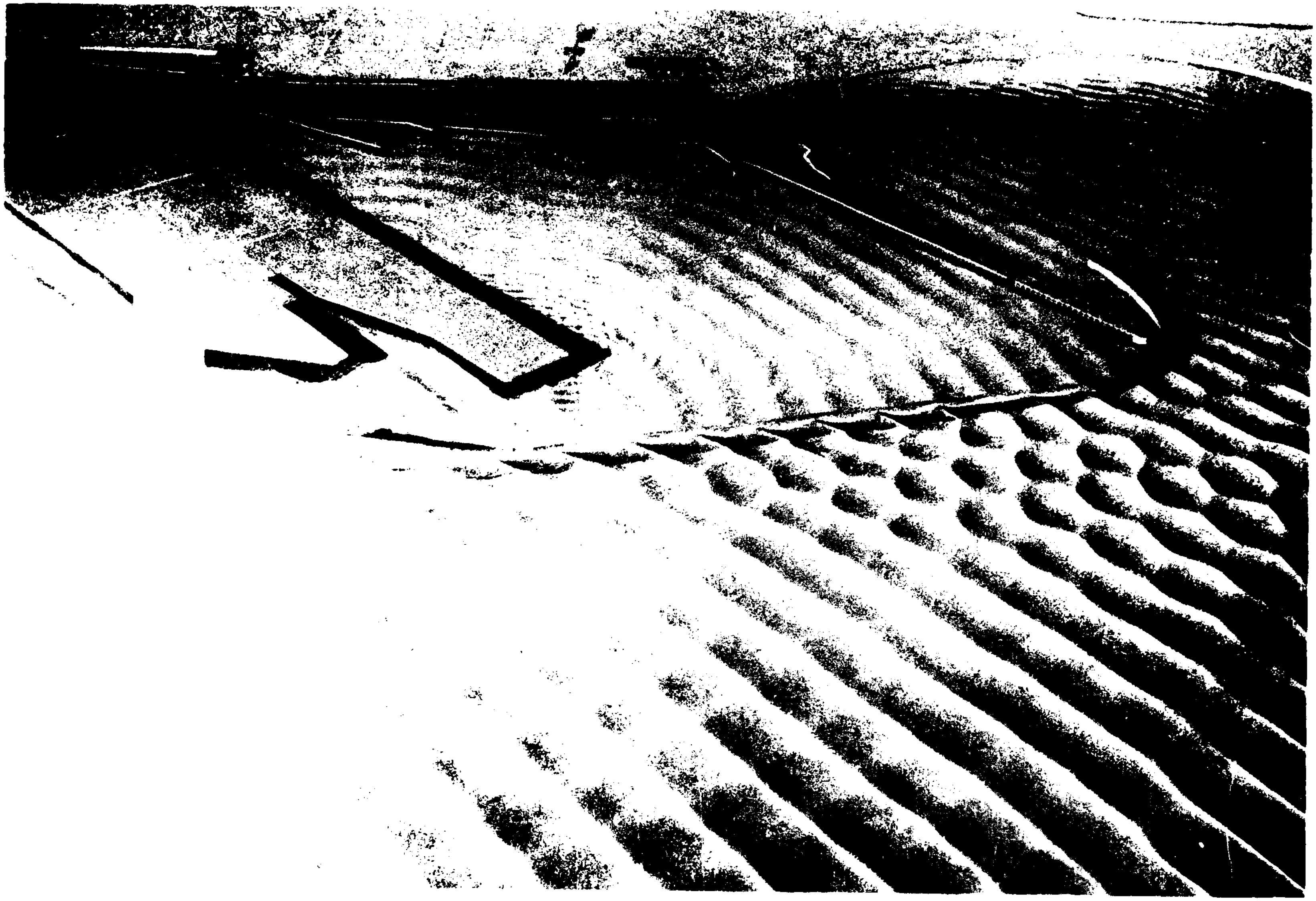


Photo 123. Typical wave patterns for Plan 63; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

Photo 124. Typical wave patterns for Plan 64; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

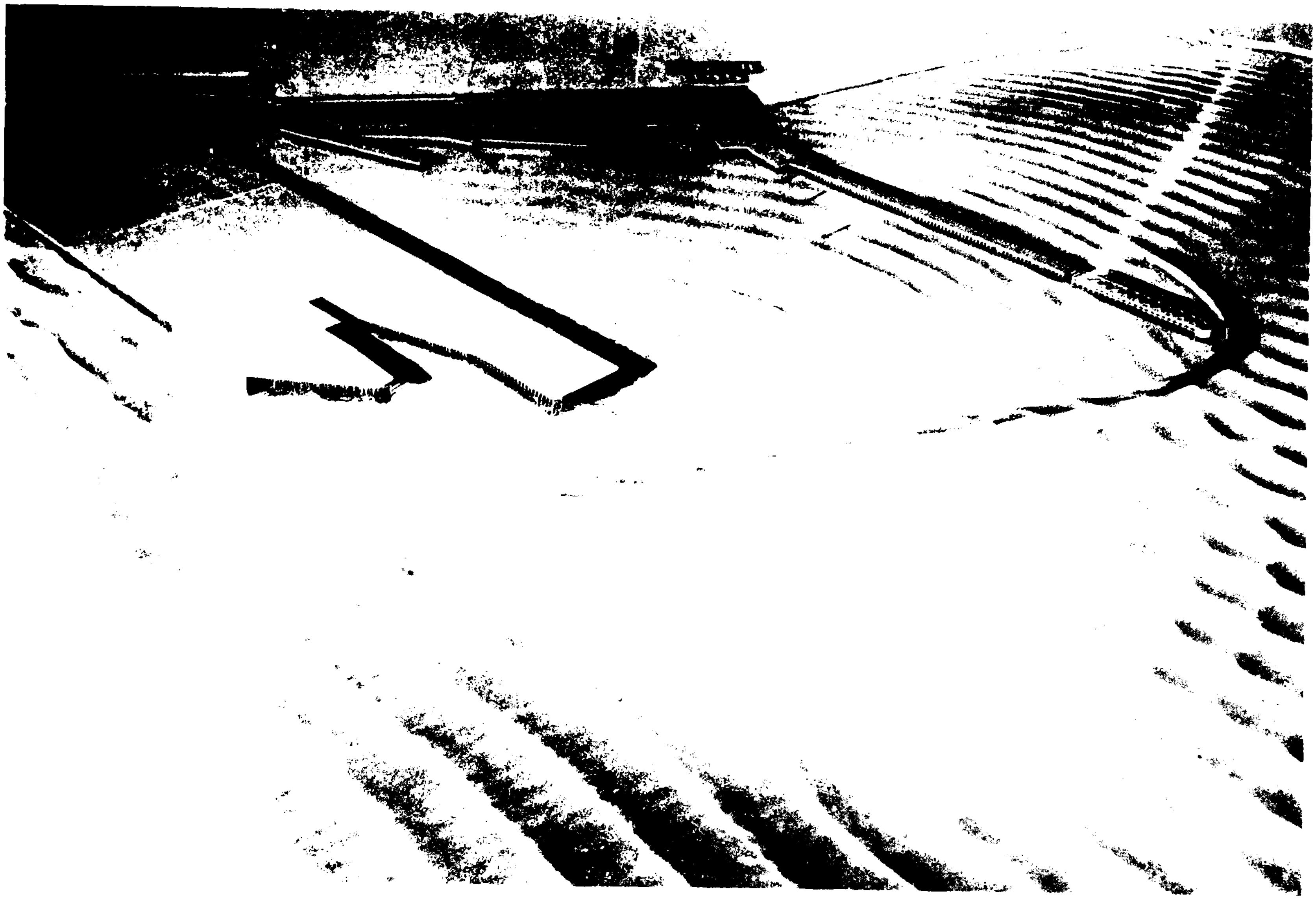


Photo 125. Typical wave patterns for Plan 65; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

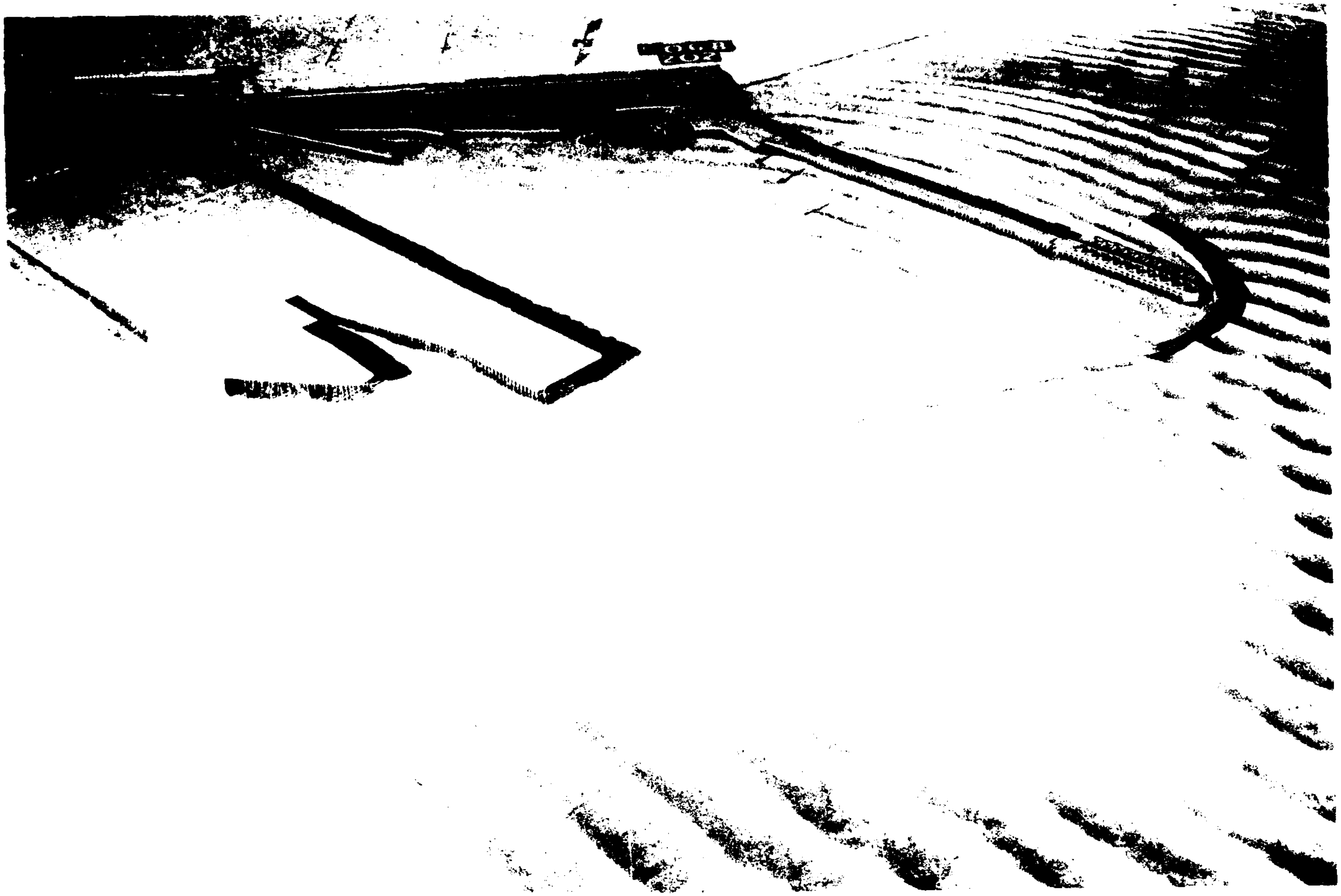


Photo 126. Typical wave patterns for Plan 66; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

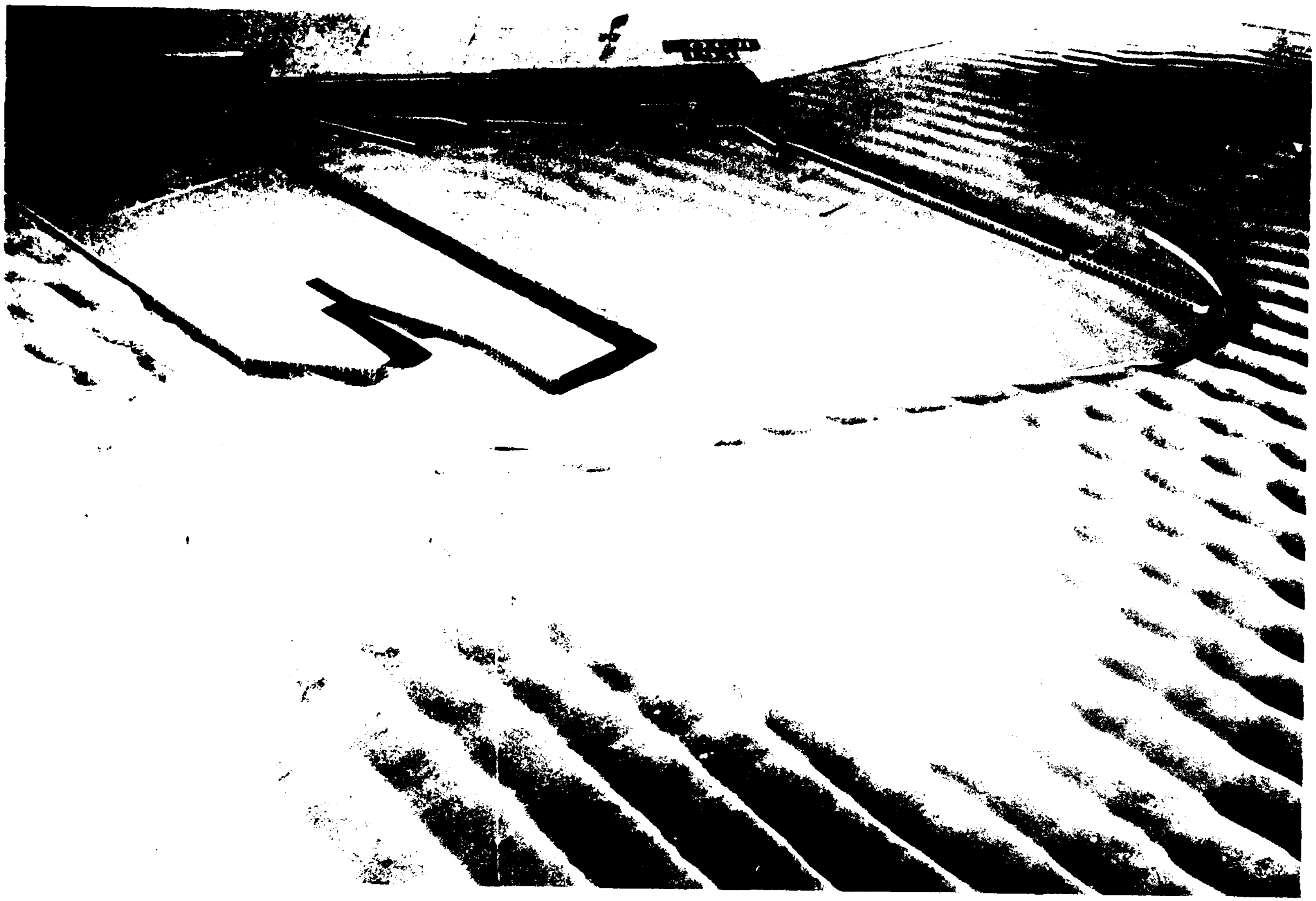


Photo 127. Typical wave patterns for Plan 67; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

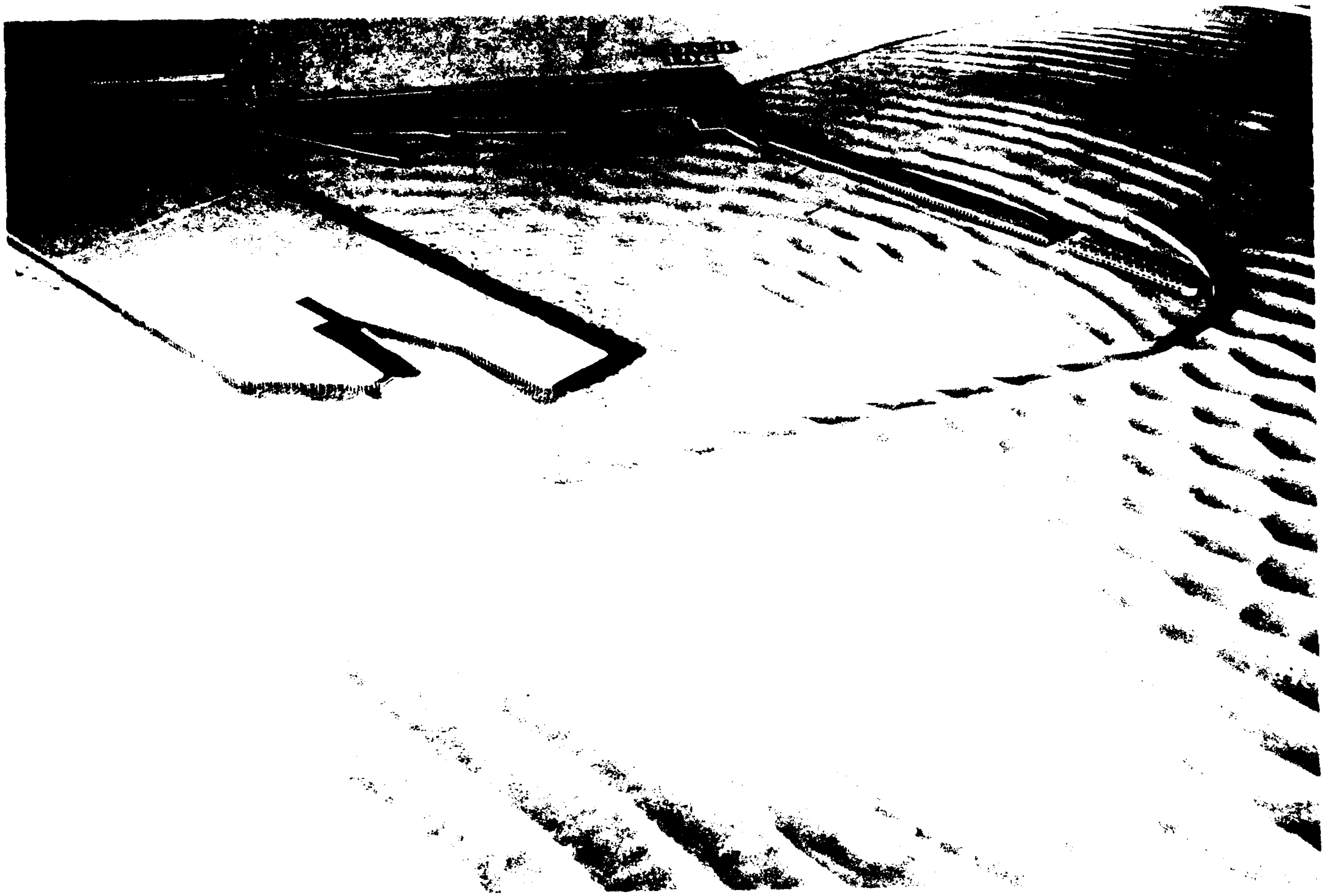


Photo 128. Typical wave patterns for Plan 68; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

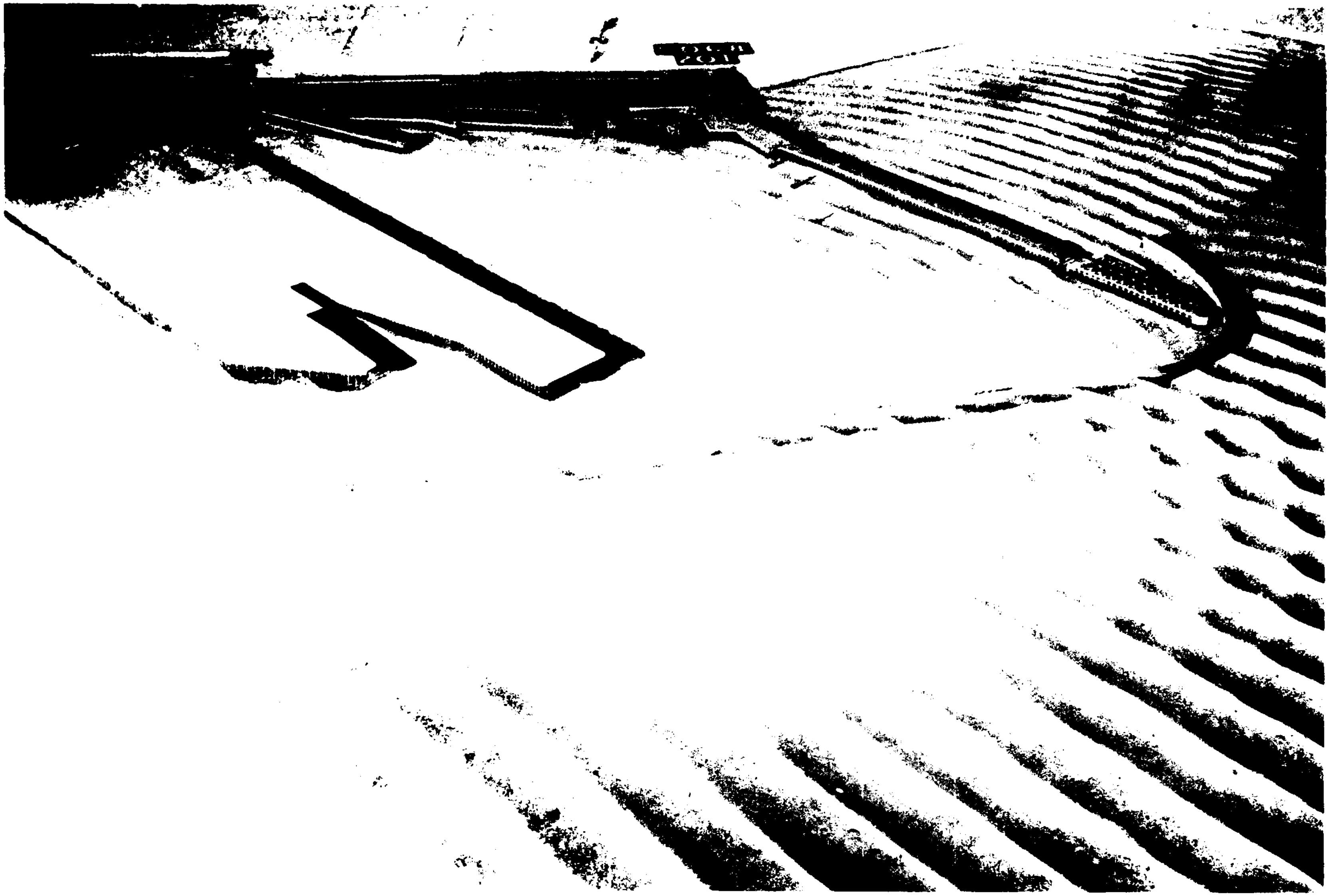


Photo 129. Typical wave patterns for Plan 69; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

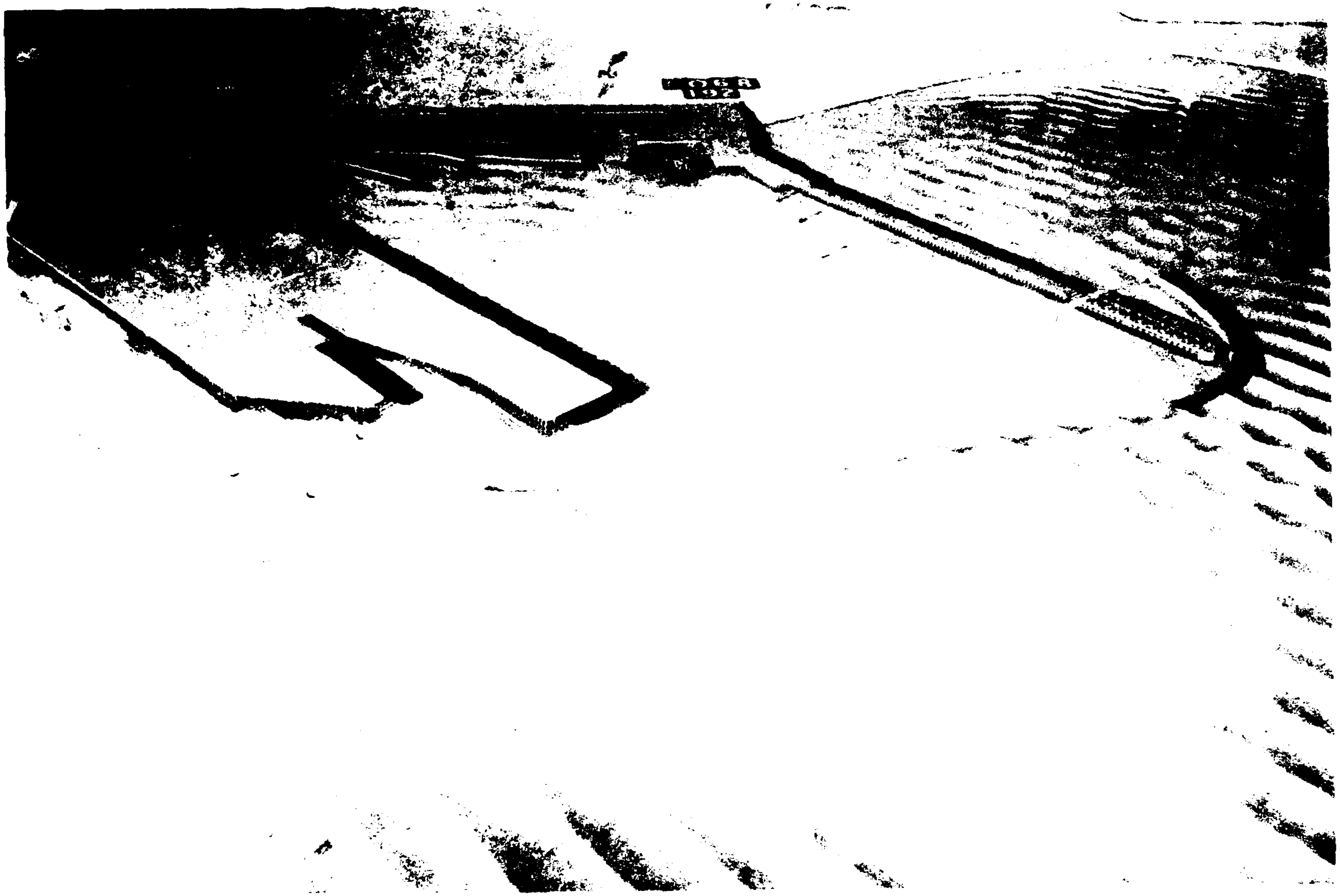


Photo 130. Typical wave patterns for Plan 70; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

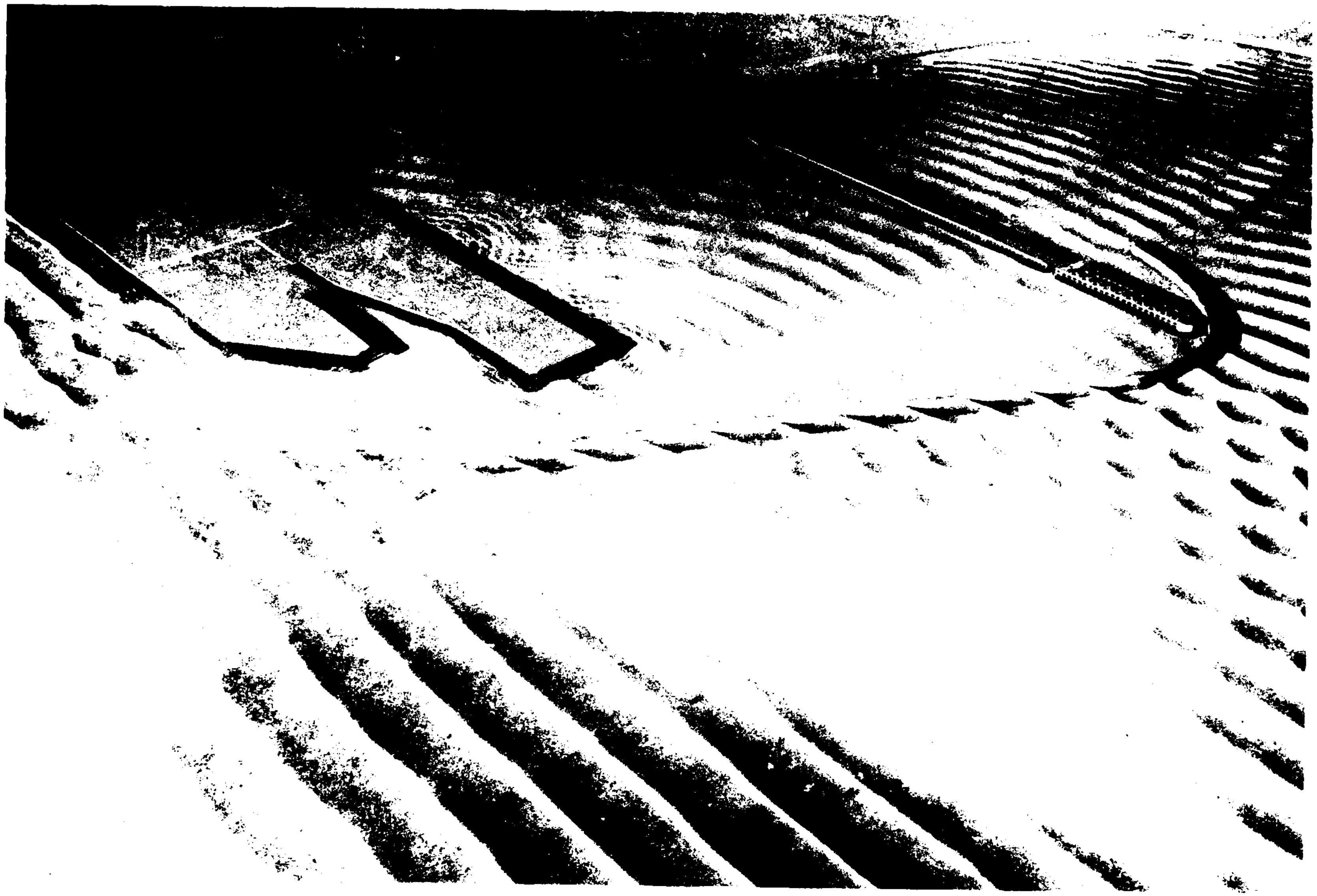


Photo 131. Typical wave patterns for Plan 71; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

Photo 132. Typical wave patterns for Plan 72; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

Photo 133. Typical wave patterns for Plan 73; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

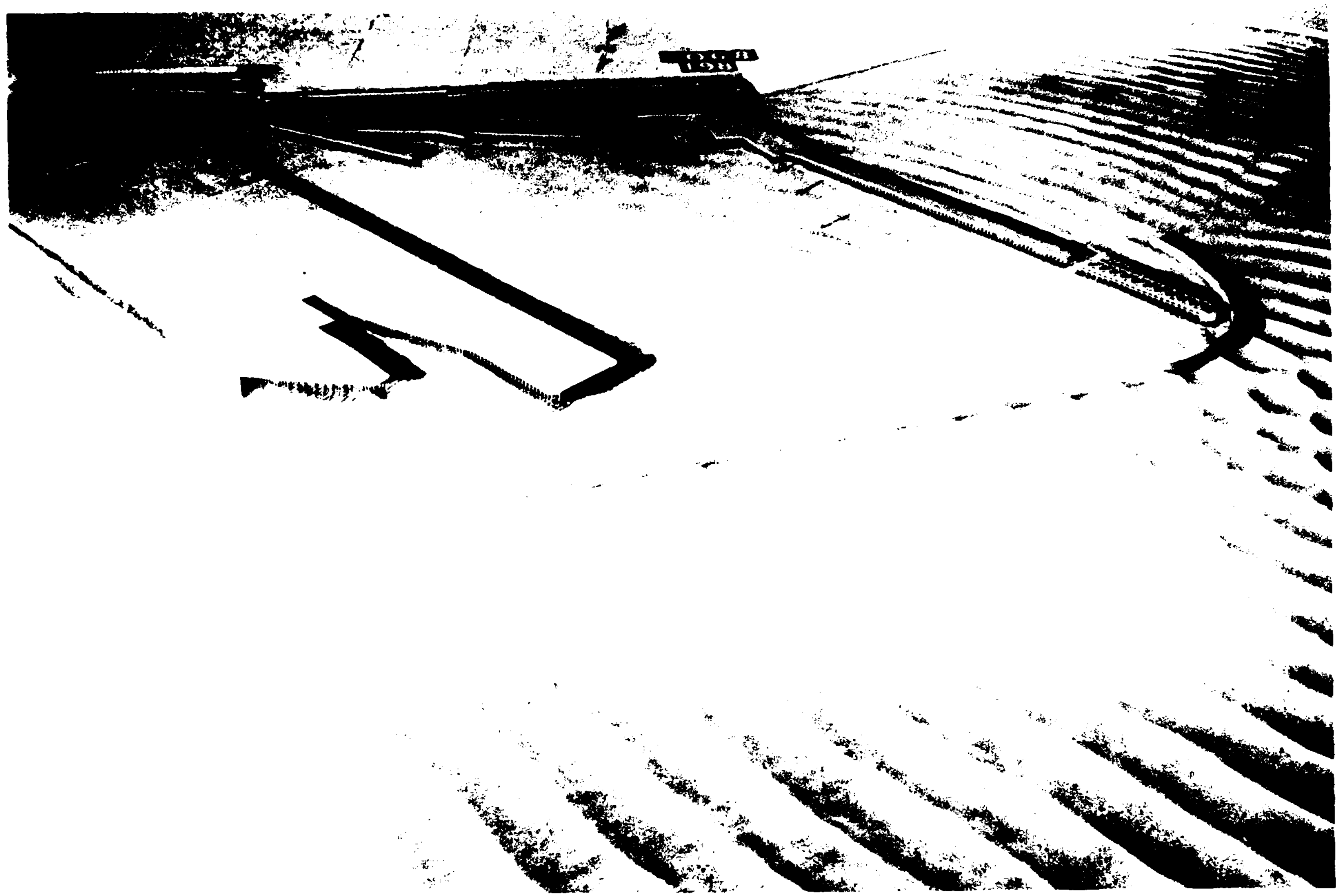


Photo 134. Typical wave patterns for Plan 74; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

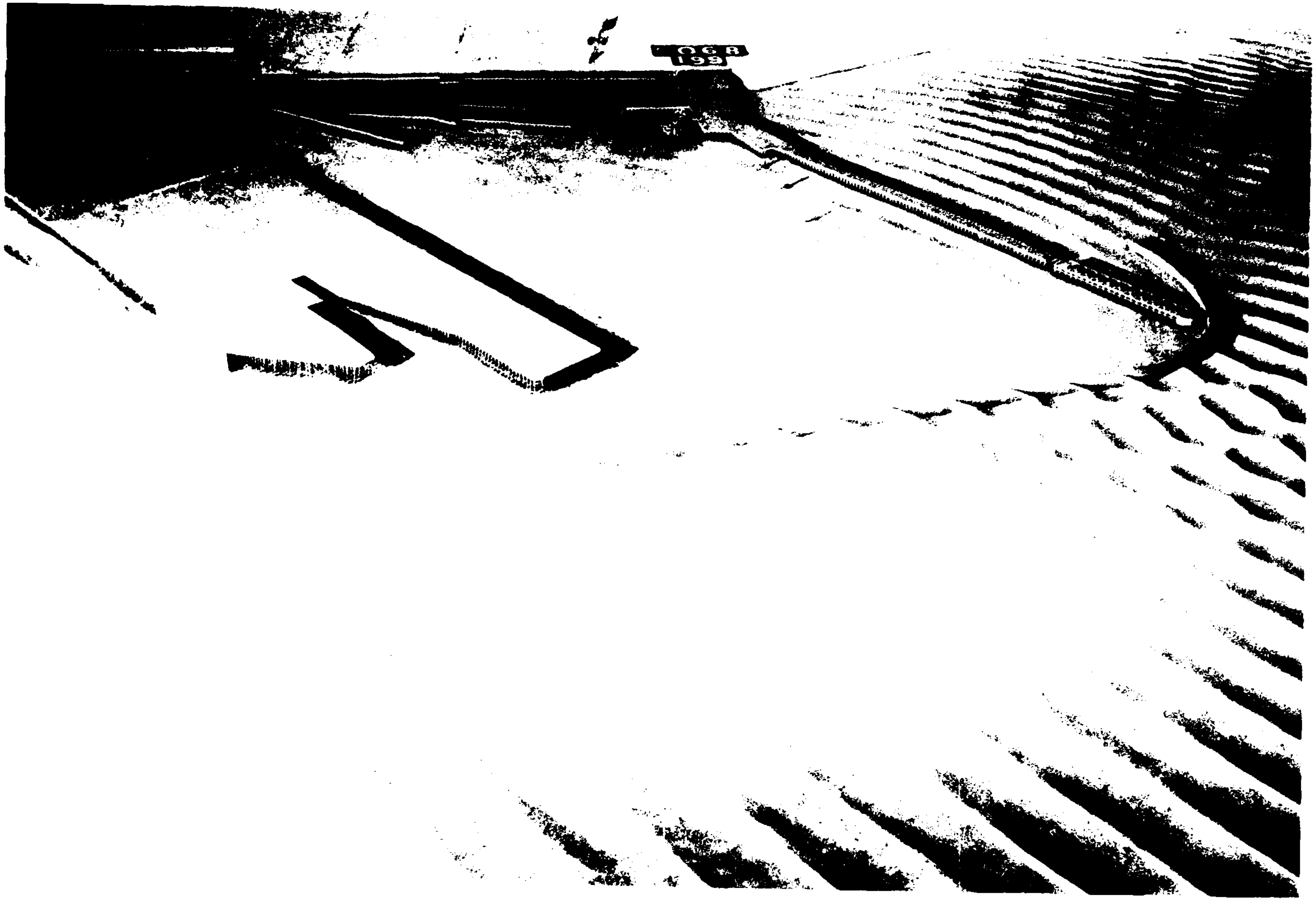


Photo 135. Typical wave patterns for Plan 75; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

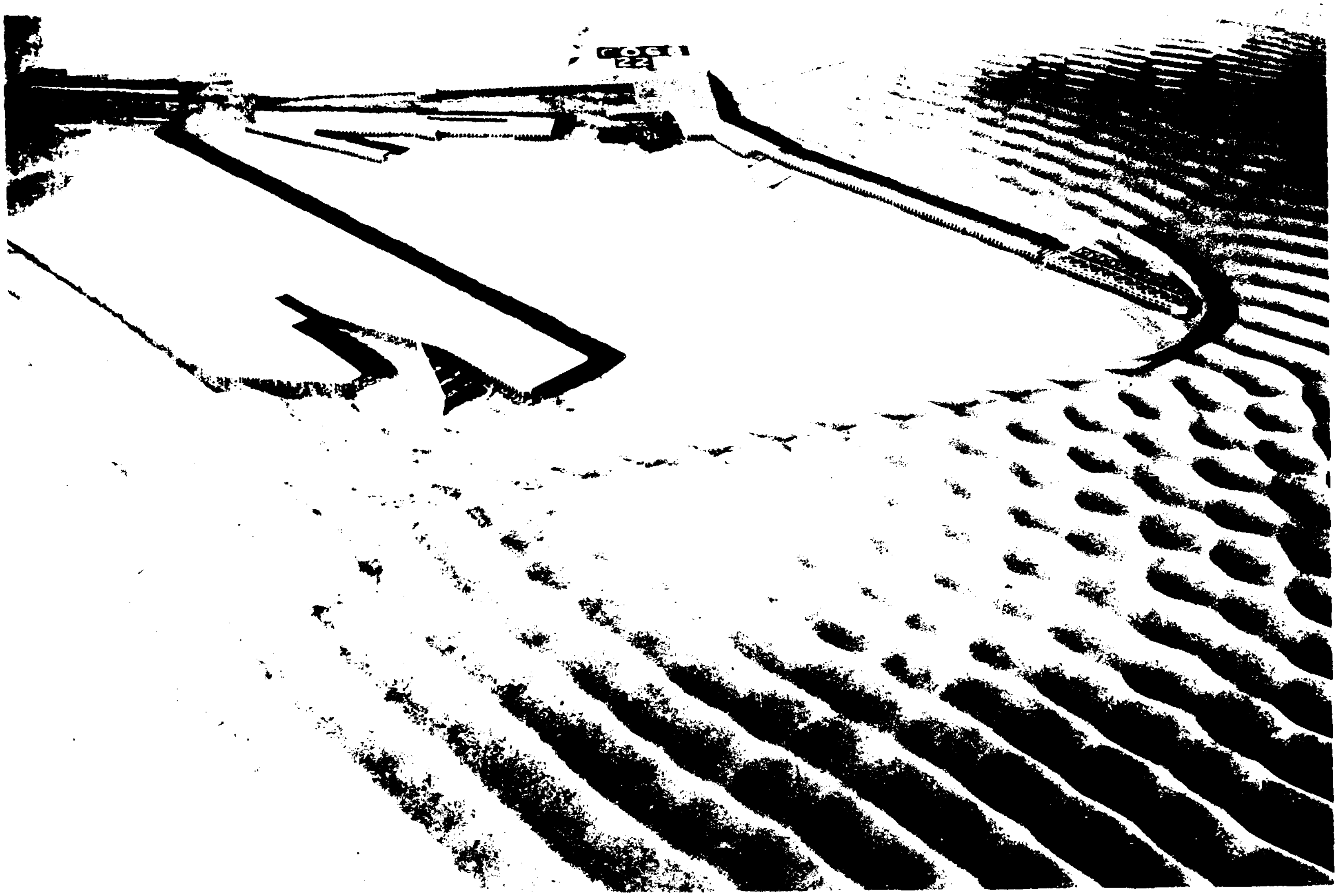


Photo 136. Typical wave patterns for Plan 76; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

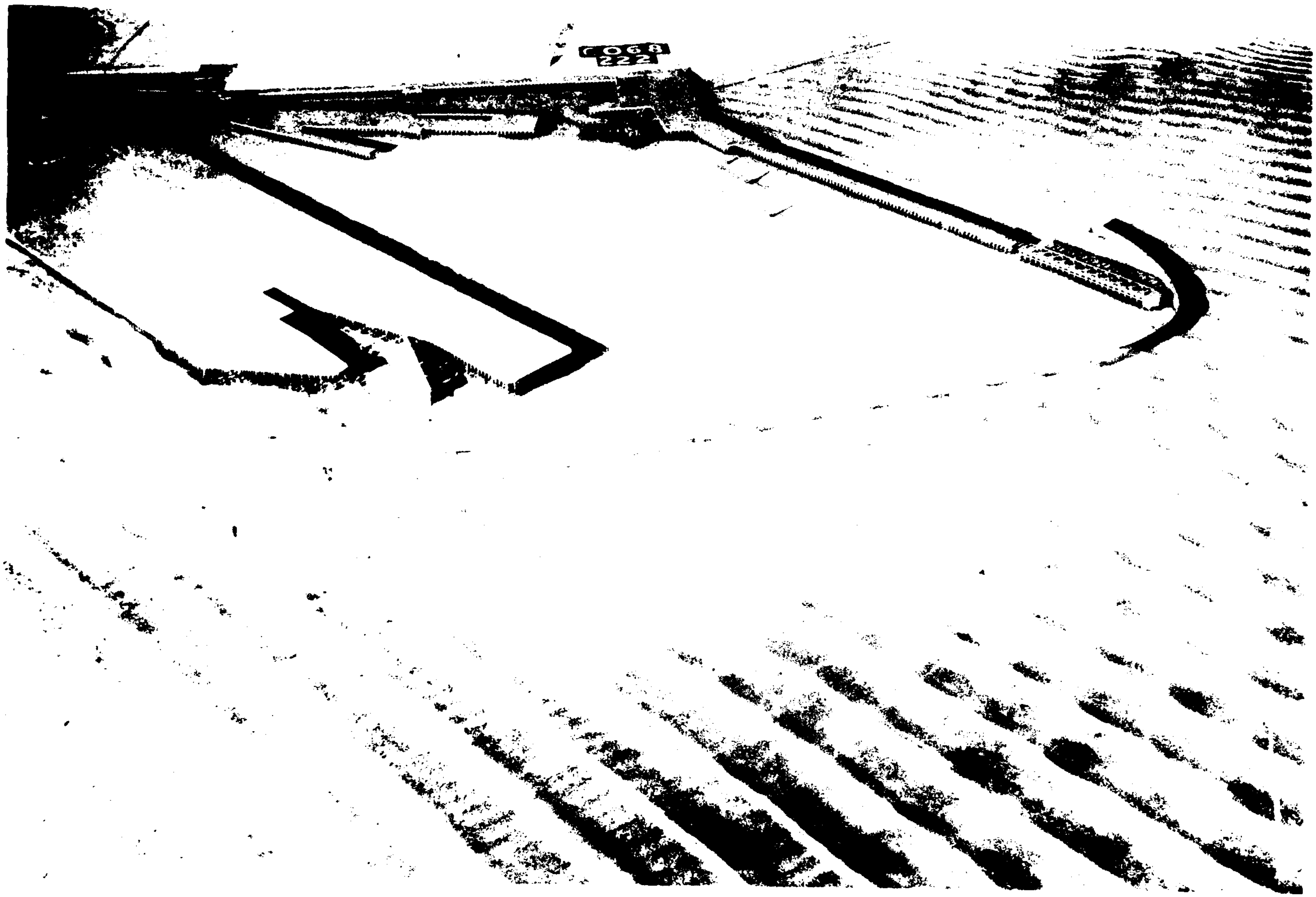


Photo 137. Typical wave patterns for Plan 77; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

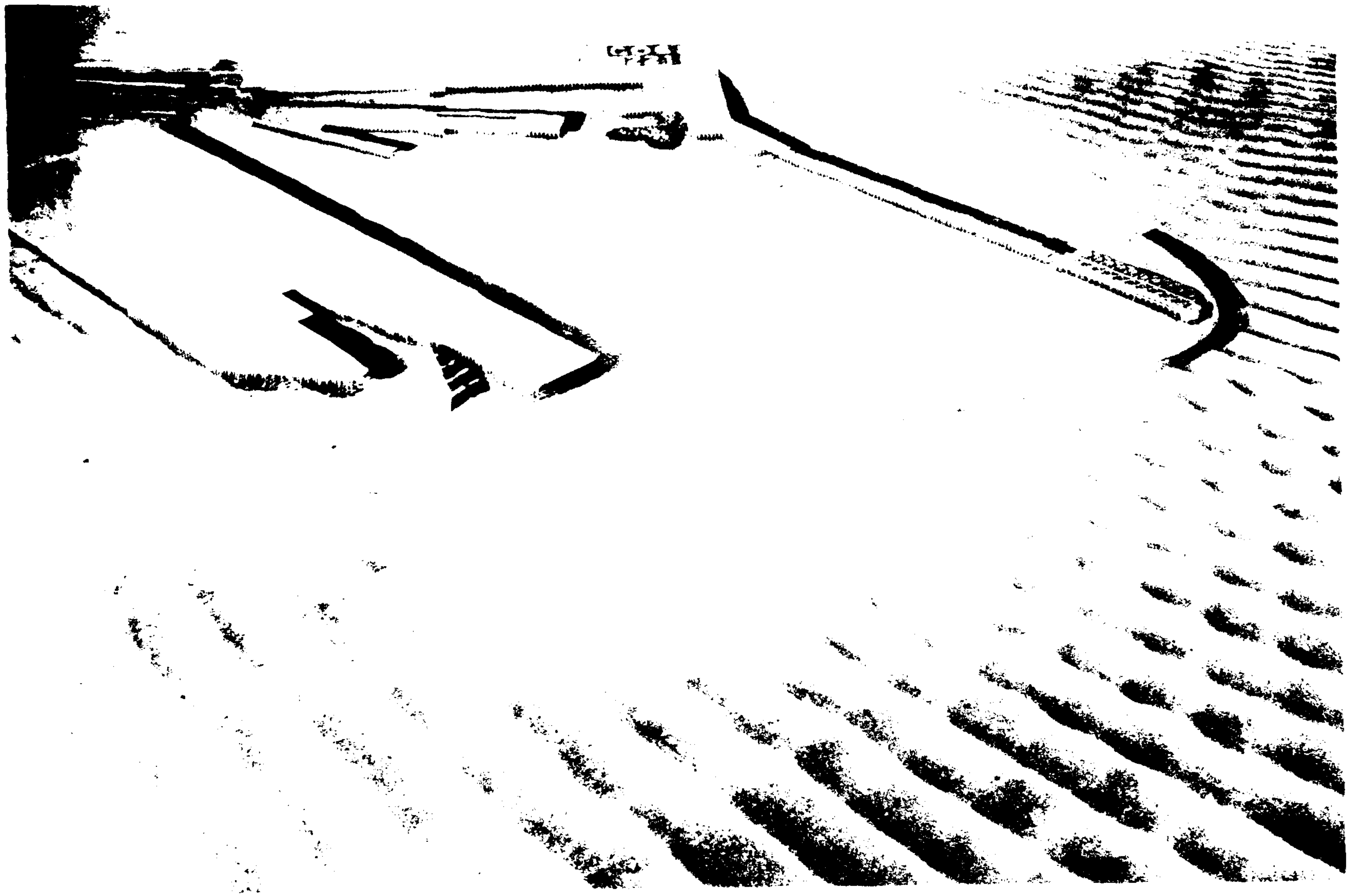


Photo 138. Typical wave patterns for Plan 78; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

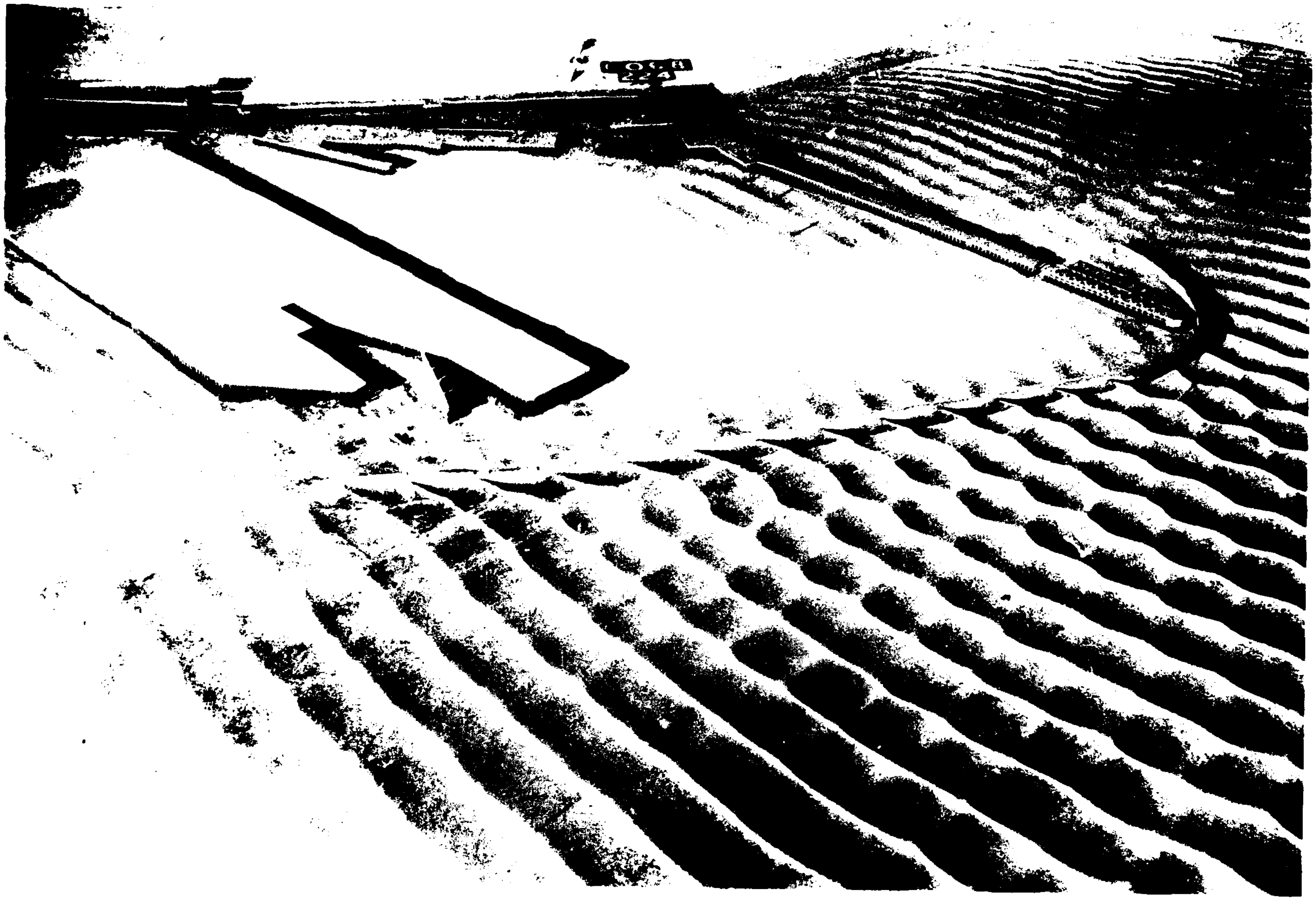


Photo 139. Typical wave patterns for Plan 79; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

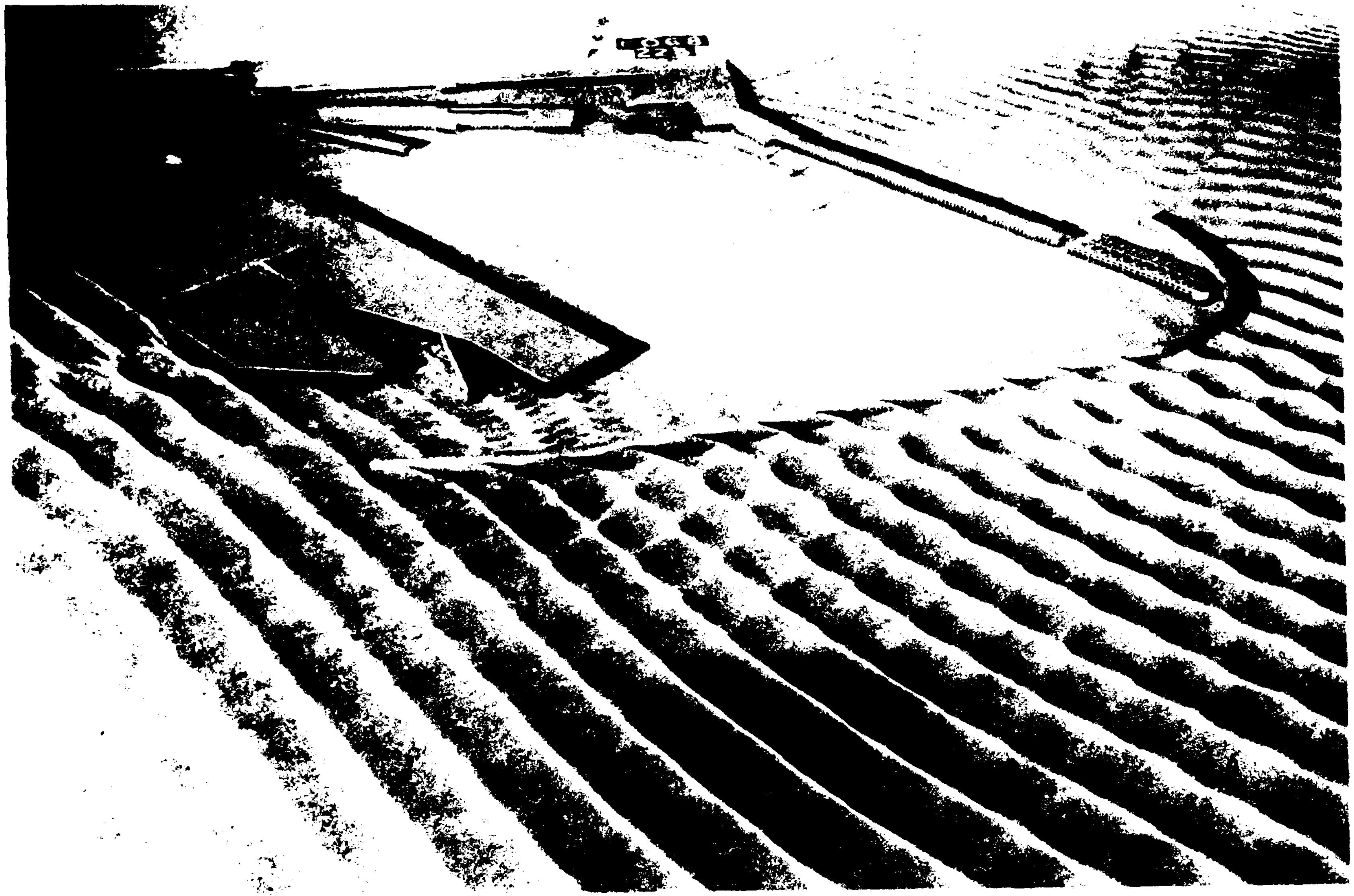


Photo 140. Typical wave patterns for Plan 80; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

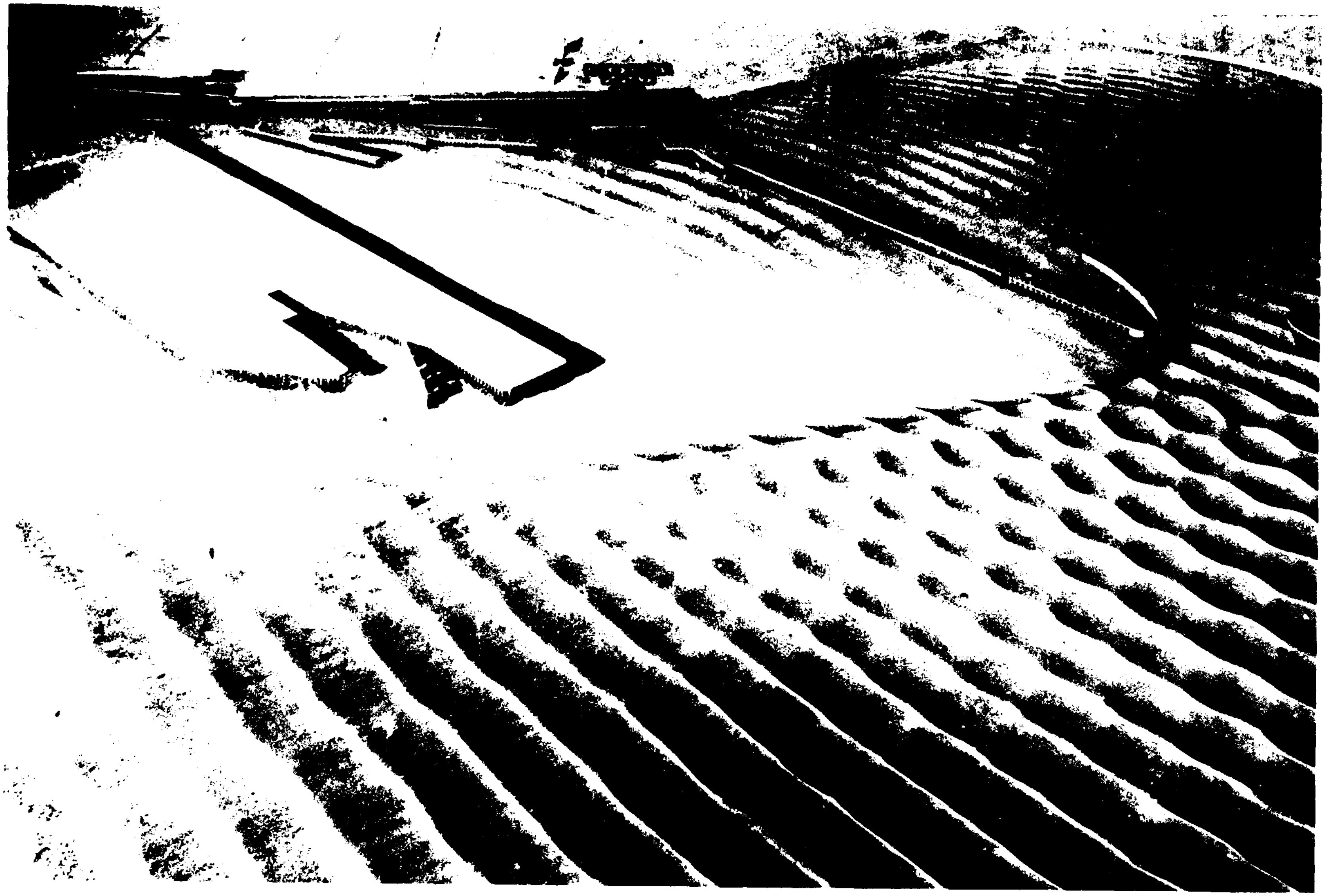


Photo 141. Typical wave patterns for Plan 81; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

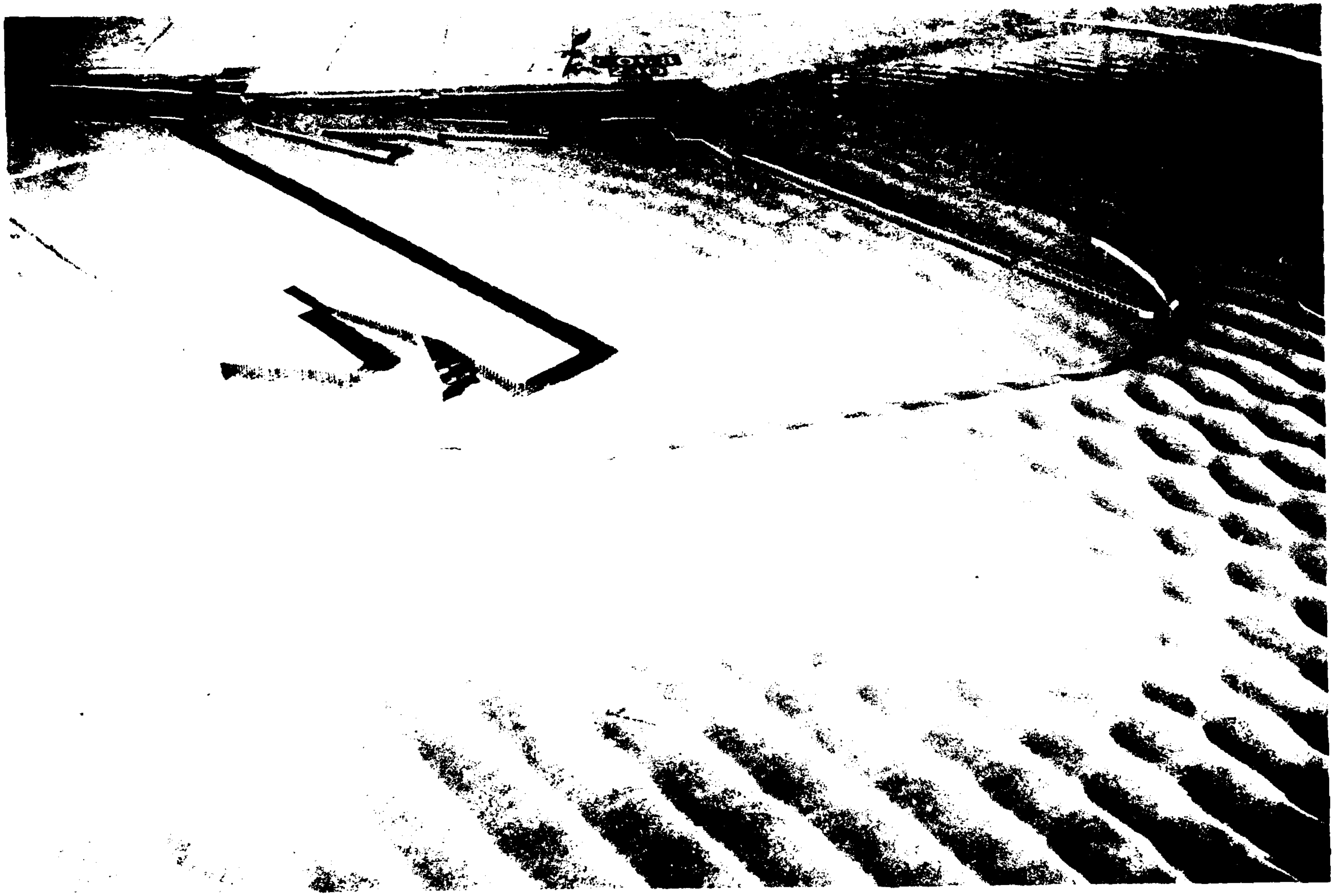


Photo 142. Typical wave patterns for Plan 82; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

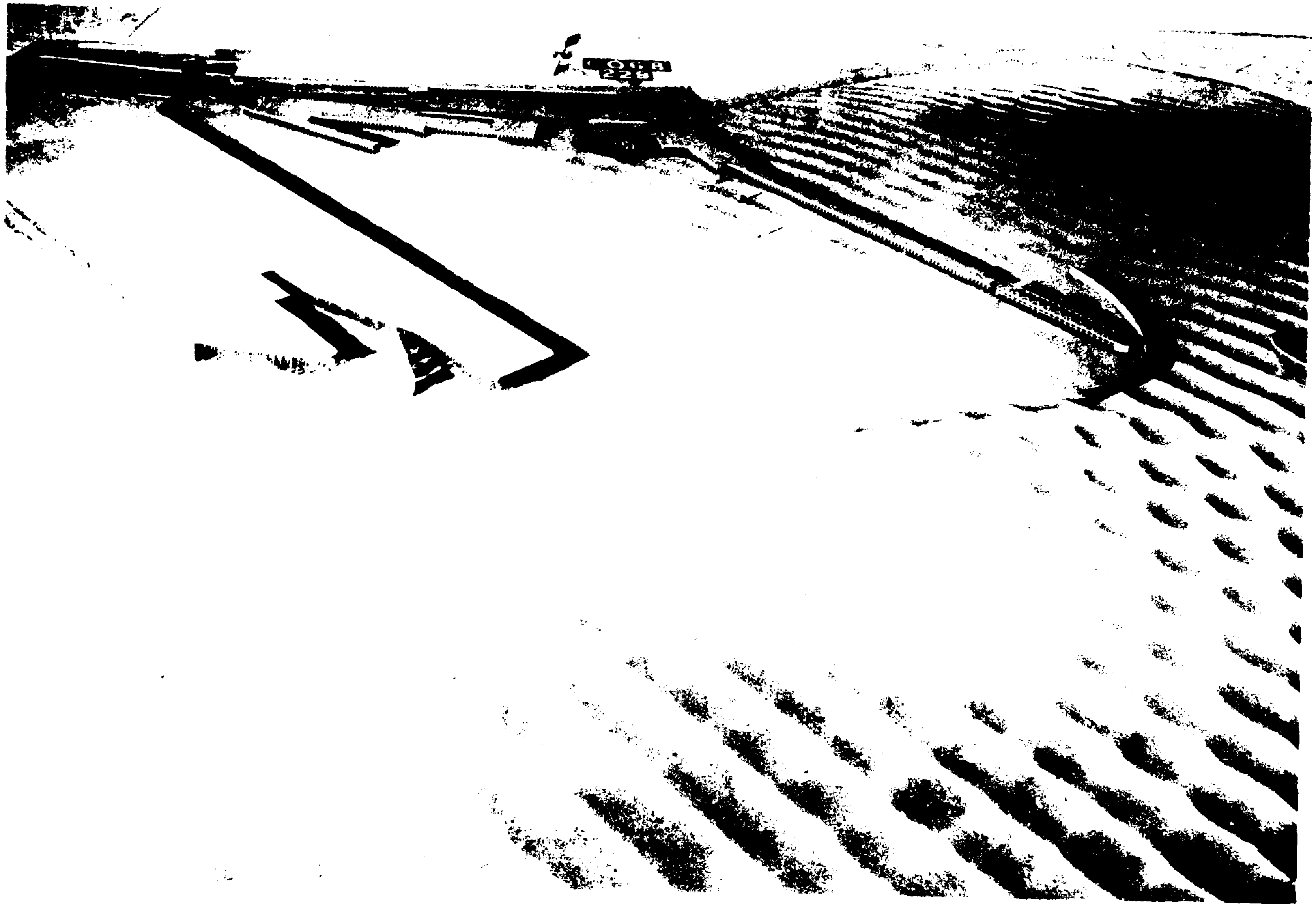


Photo 143. Typical wave patterns for Plan 83; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

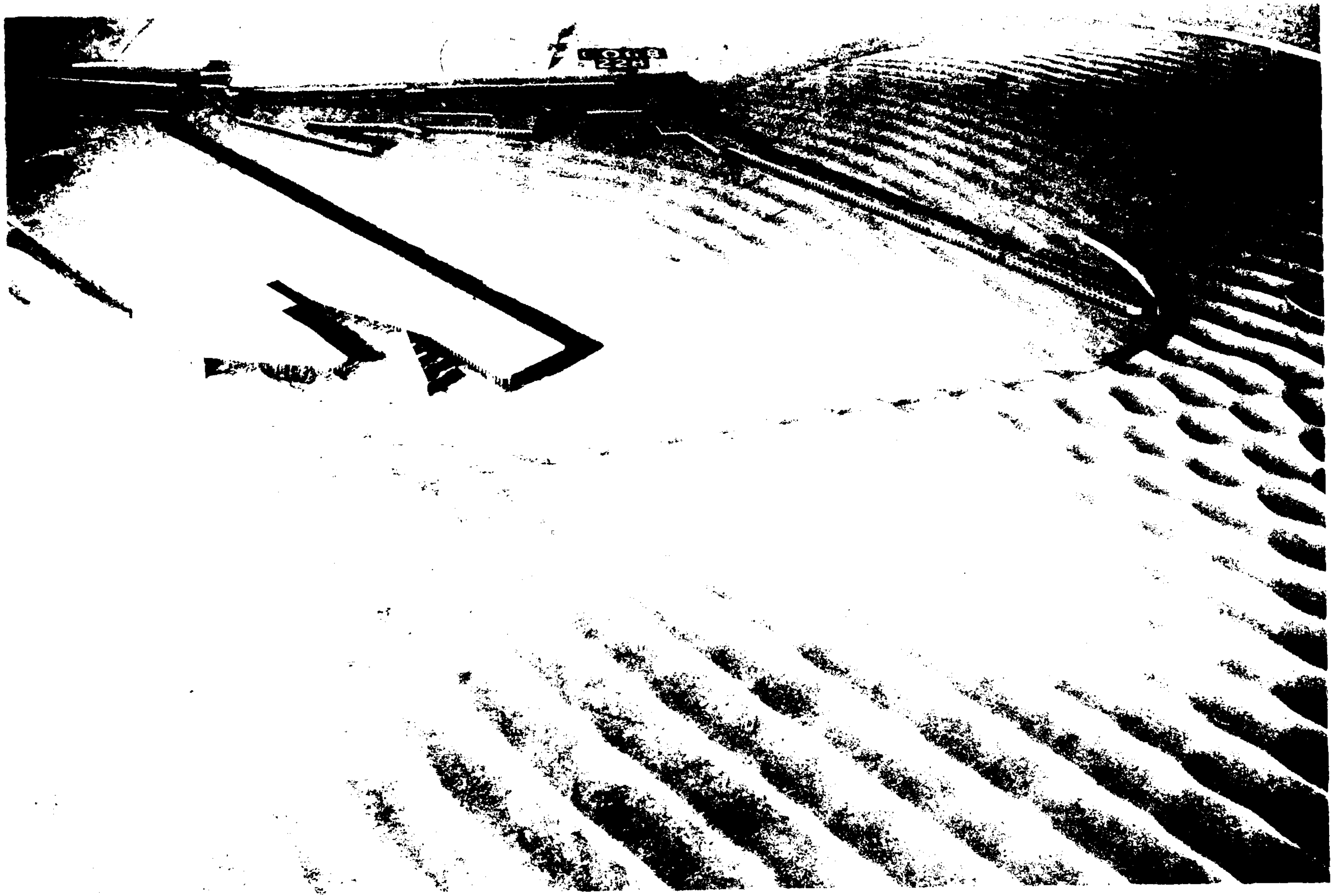


Photo 144. Typical wave patterns for Plan 84; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

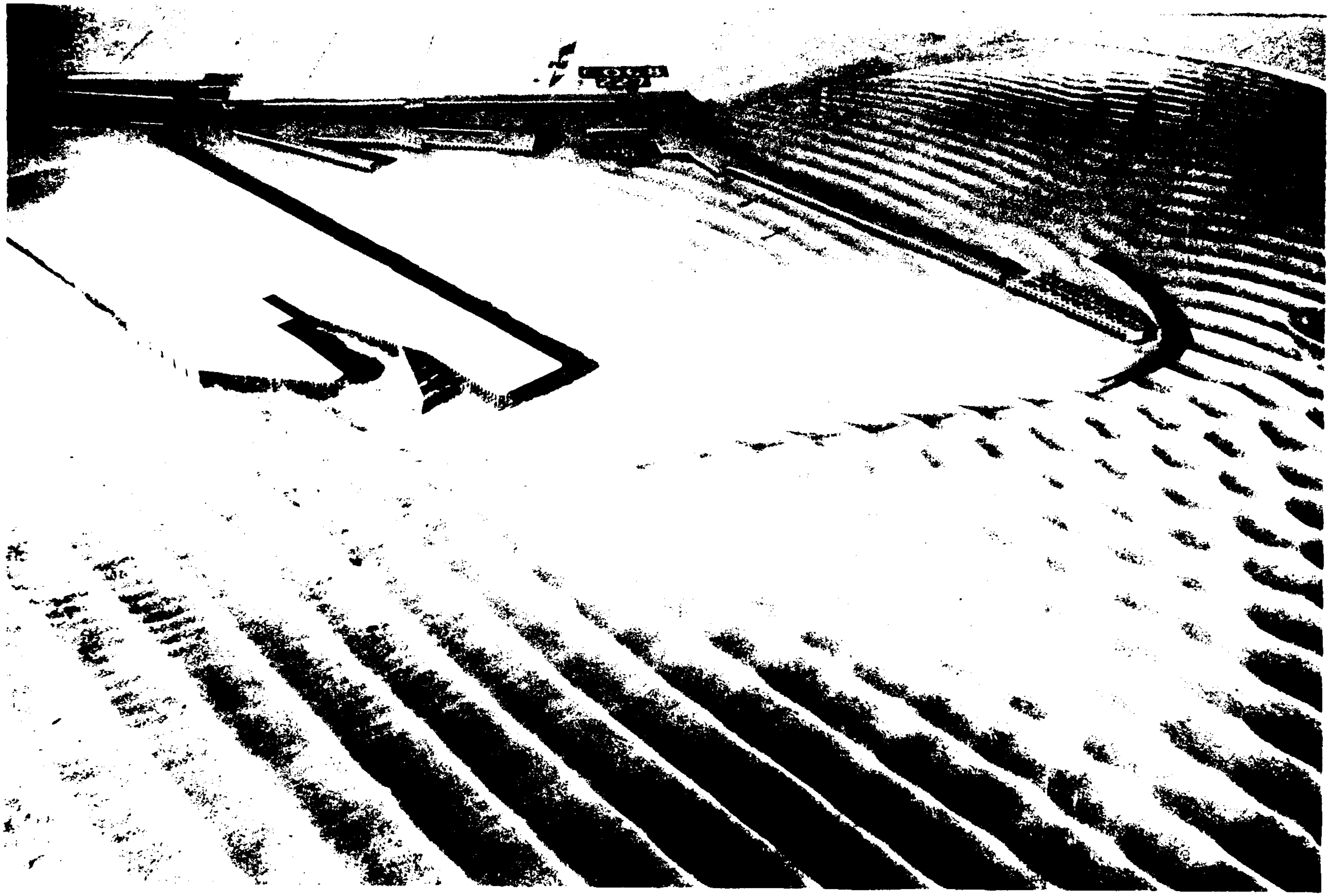


Photo 145. Typical wave patterns for Plan 85; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

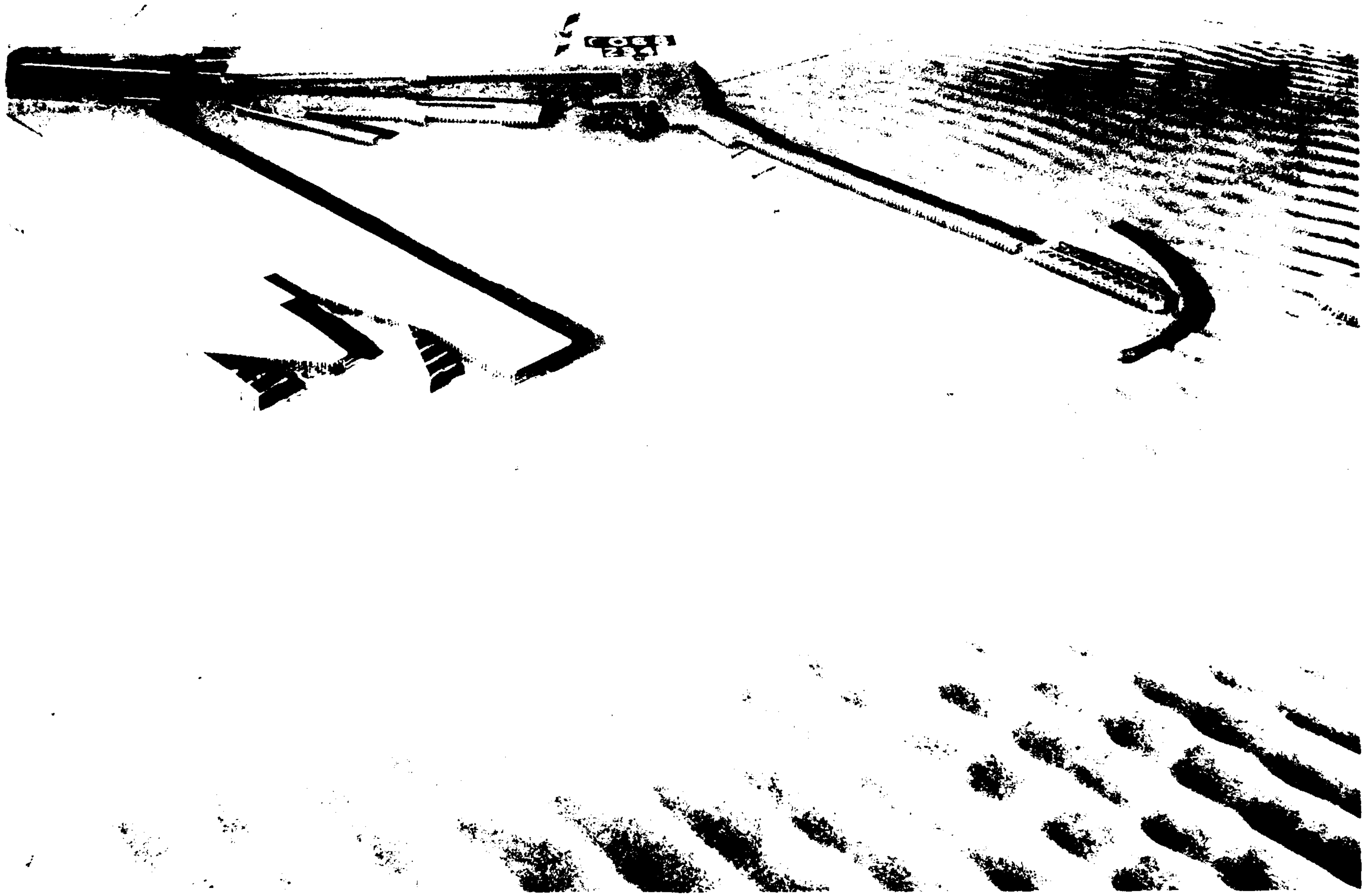


Photo 146. Typical wave patterns for Plan 86; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

Photo 147. Typical wave patterns for Plan 87; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

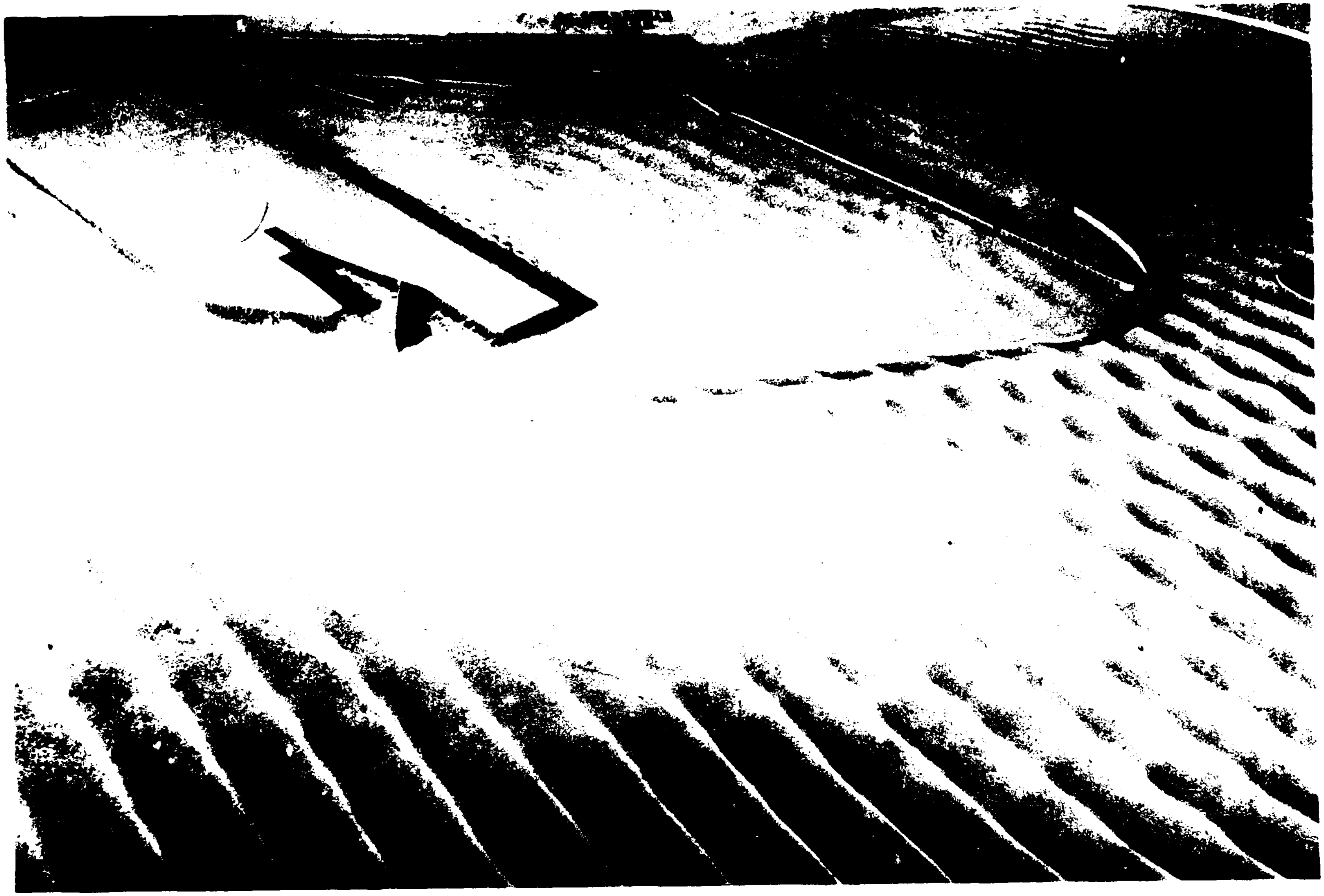


Photo 148. Typical wave patterns for Plan 88; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

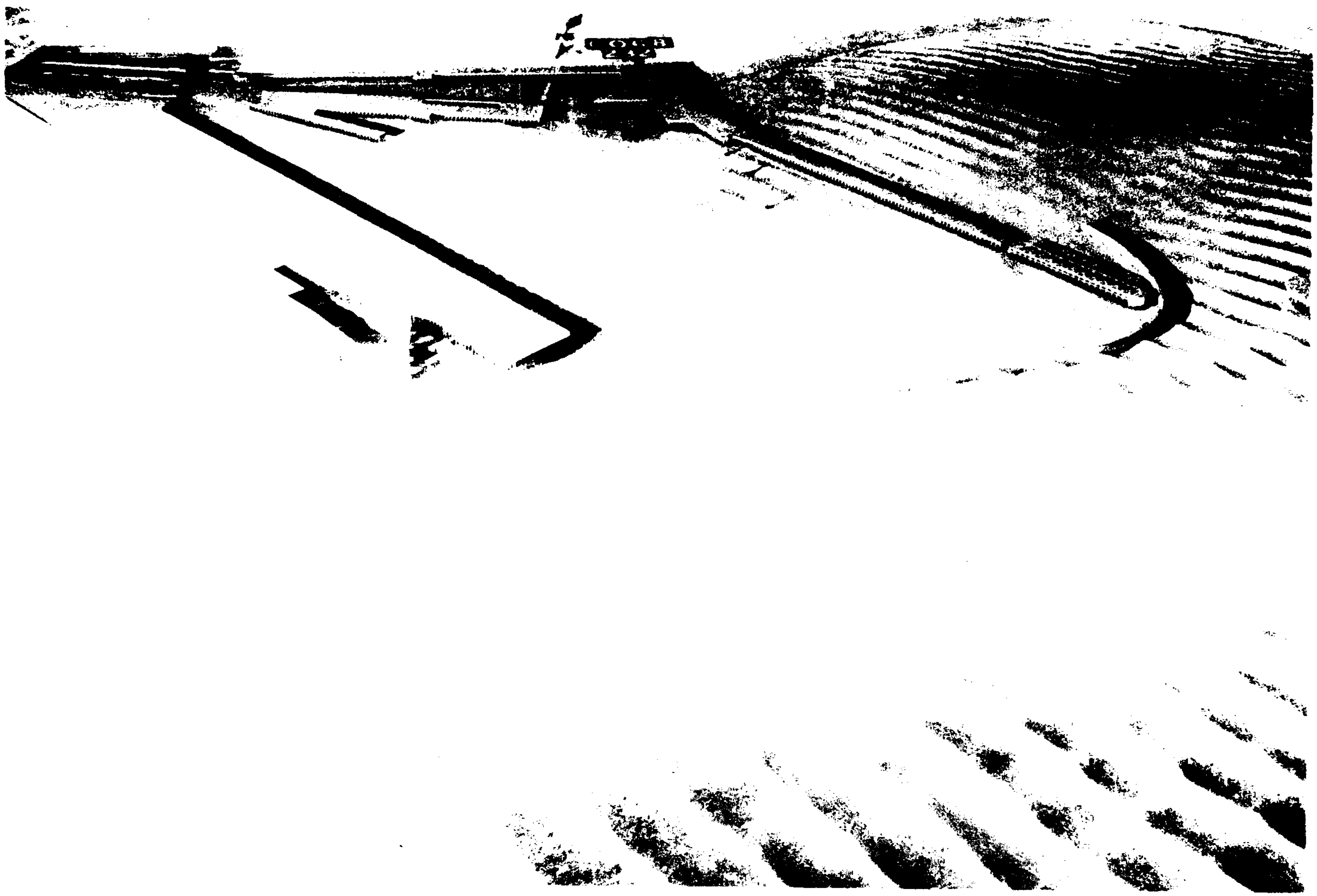


Photo 149. Typical wave patterns for Plan 89; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

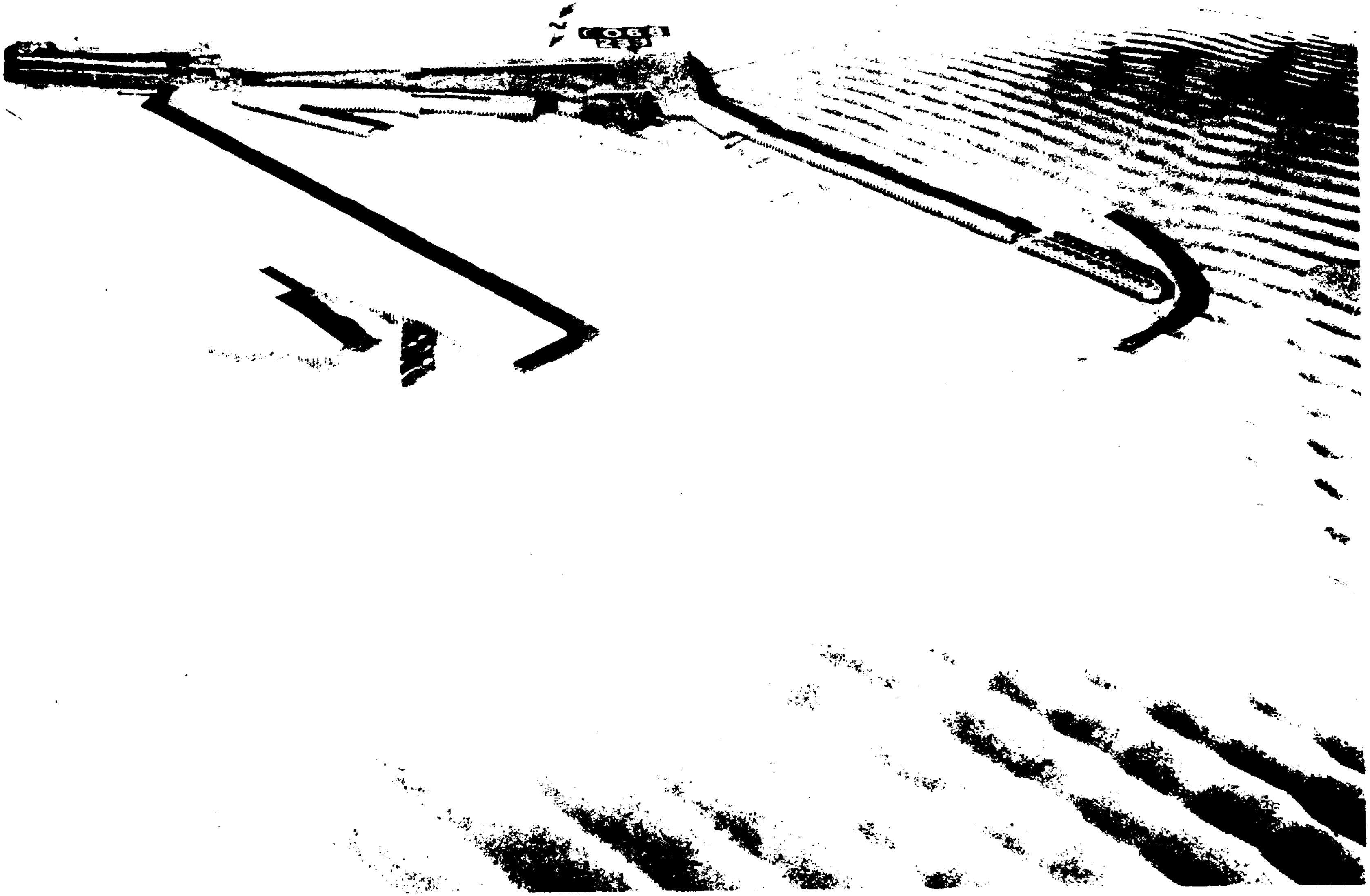


Photo 150. Typical wave patterns for Plan 90; 3.9-sec, 3.3-ft waves from northeast; 0.0-ft swl

Photo 151. Typical wave patterns for Plan 78; 3.6-sec, 2.0-ft waves from northeast; +5.7 ft swl

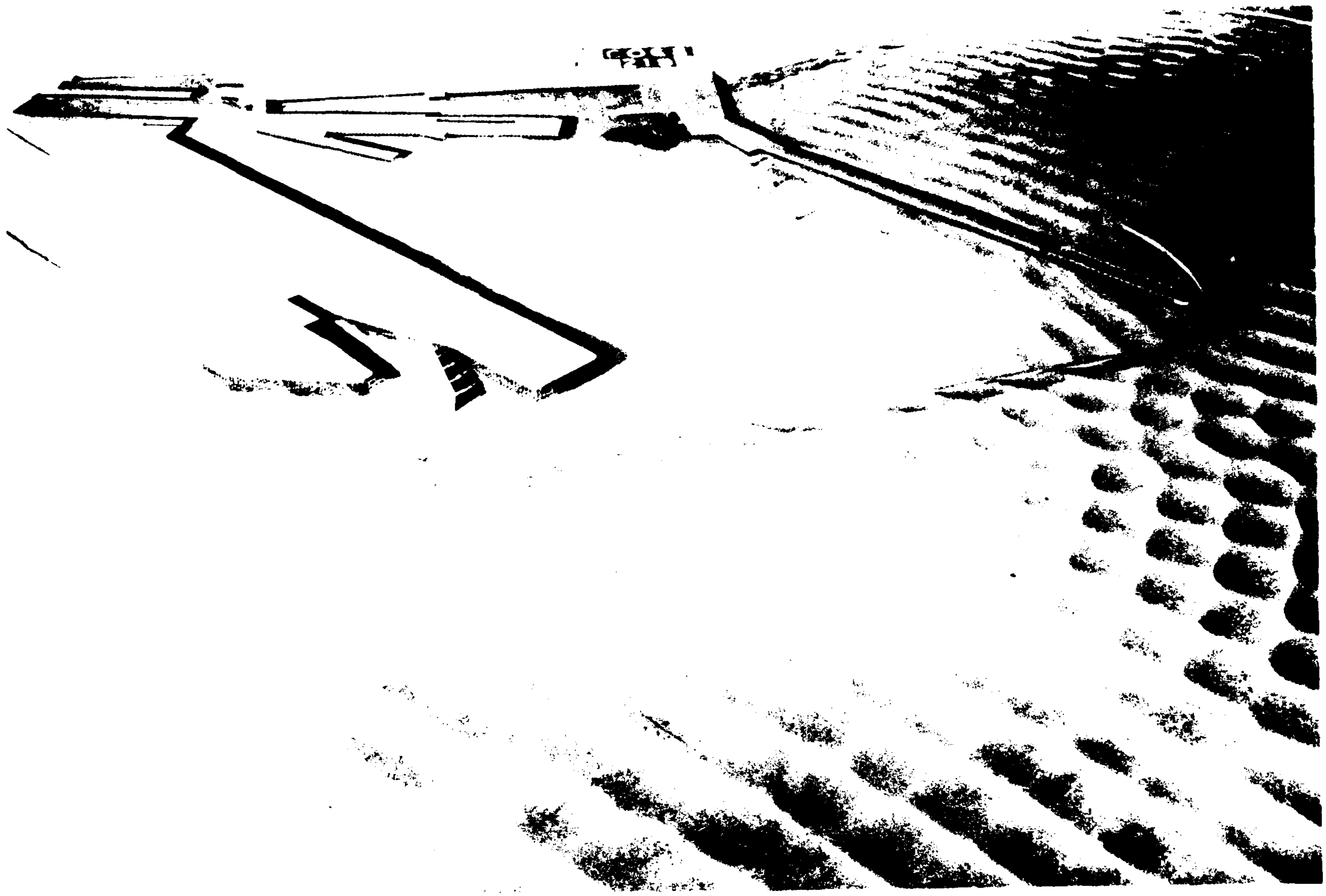


Photo 152. Typical wave patterns for Plan 78; 3.9-sec, 3.3-ft waves from northeast; +5.7 ft swl

Photo 153. Typical wave patterns for Plan 78; 3.6-sec, 2.5-ft waves from north-northeast; +5.7 ft swl

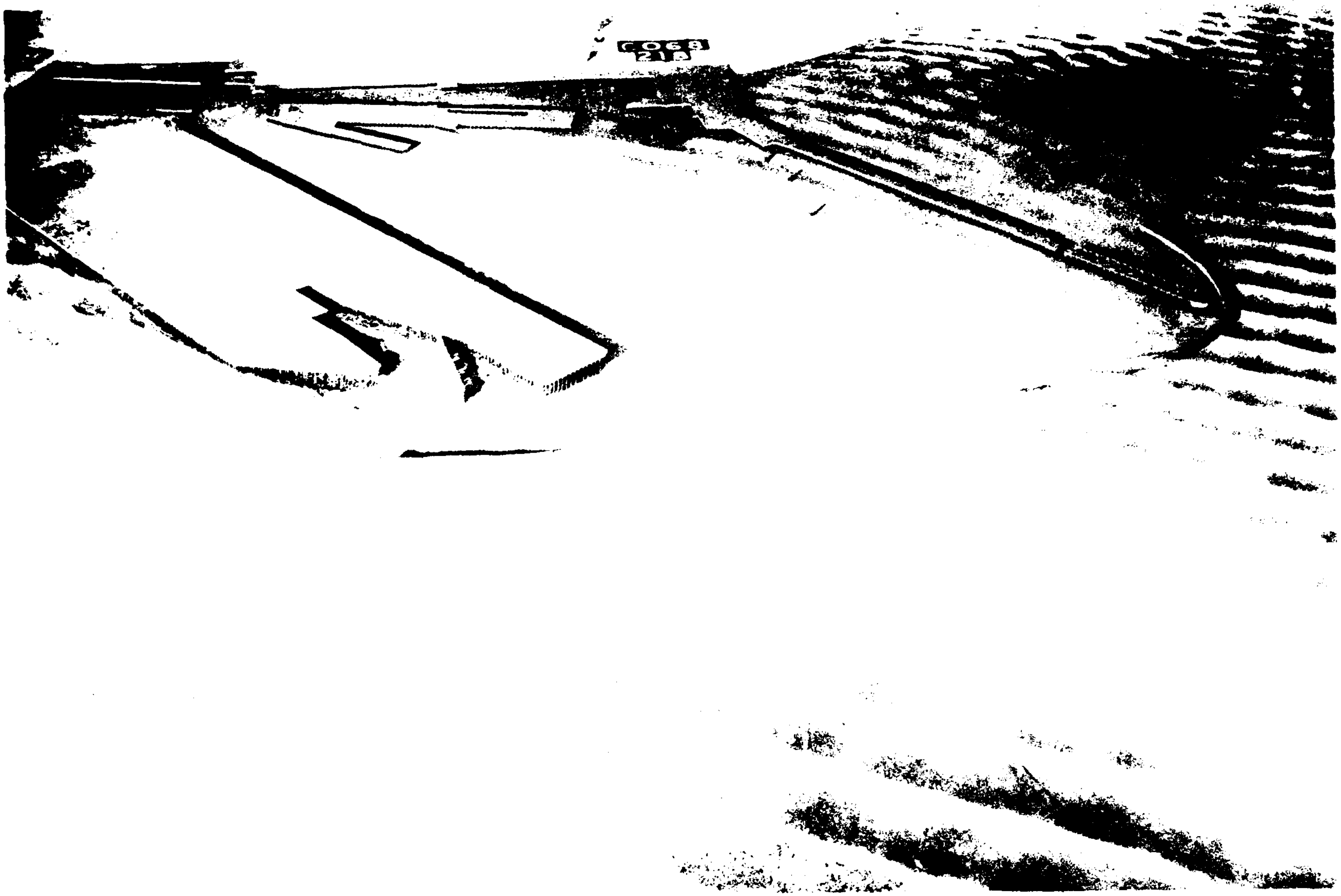


Photo 154. Typical wave patterns for Plan 78; 4.2-sec, 4.8-ft waves from north-northeast; +5.7 ft swl

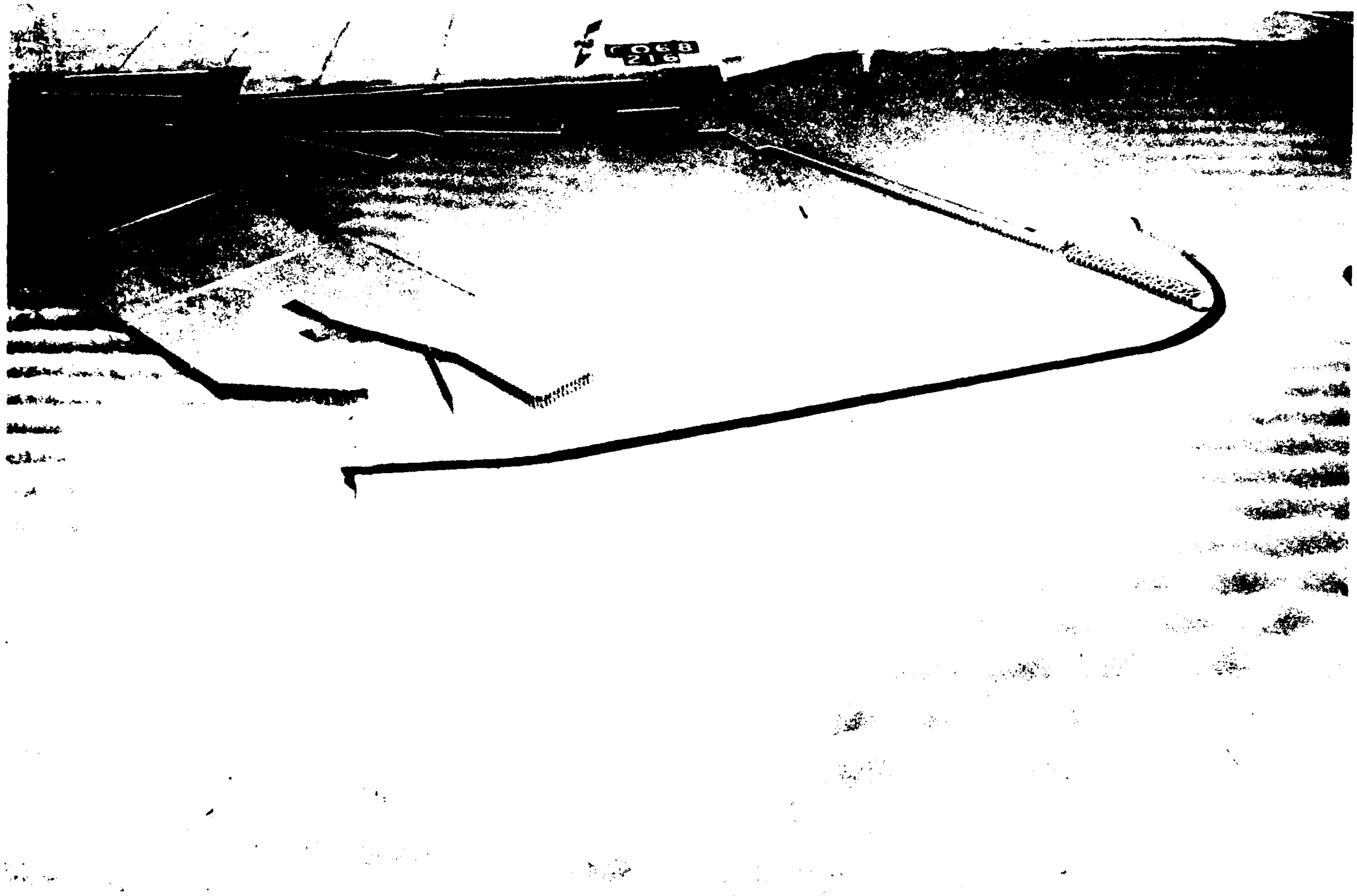


Photo 155. Typical wave patterns for Plan 78; 3.6-sec, 2.0-ft waves from north; +5.7 ft swl

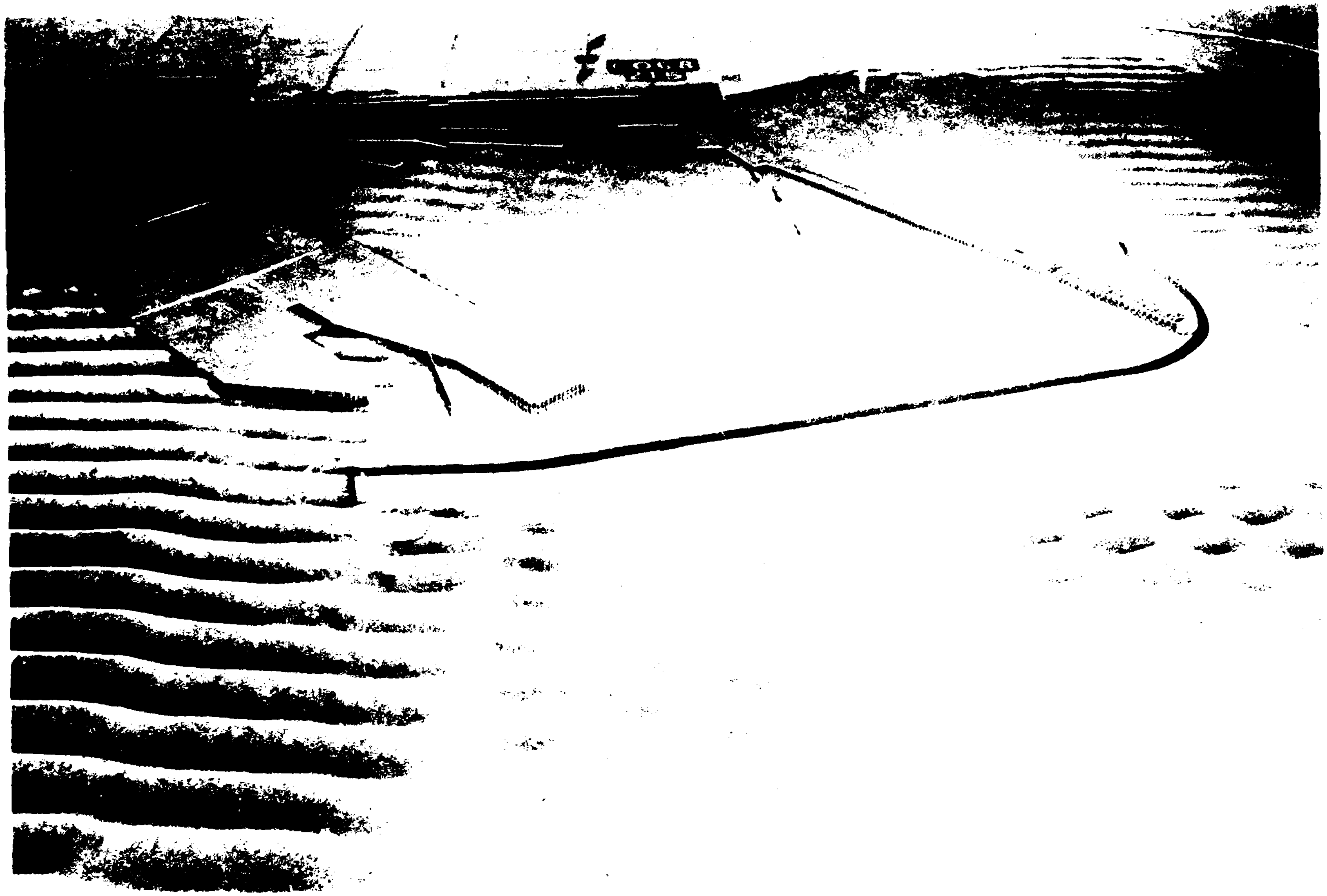


Photo 156. Typical wave patterns for Plan 78; 3.6-sec, 3.1-ft waves from north; +5.7 ft swl

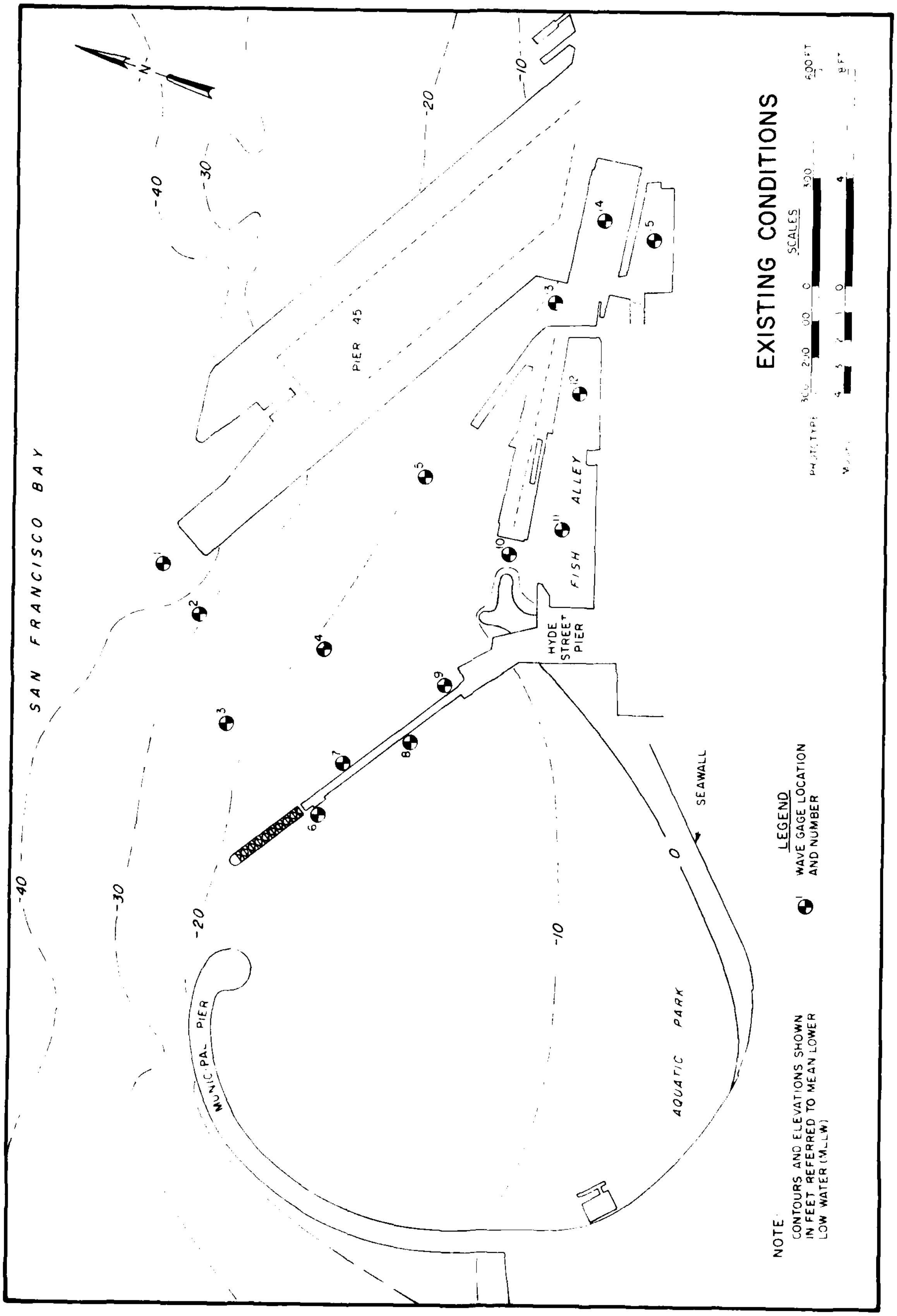

EXISTING CONDITIONS
SCALES
PROTOTYPE
MODEL
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SAN FRANCISCO BAY
PIER 45
FISH ALLEY
HYDE STREET PIER
SEAWALL
AQUATIC PARK
MUNICIPAL PIER
N
-40
-30
-20
-10
0

PLATE 1

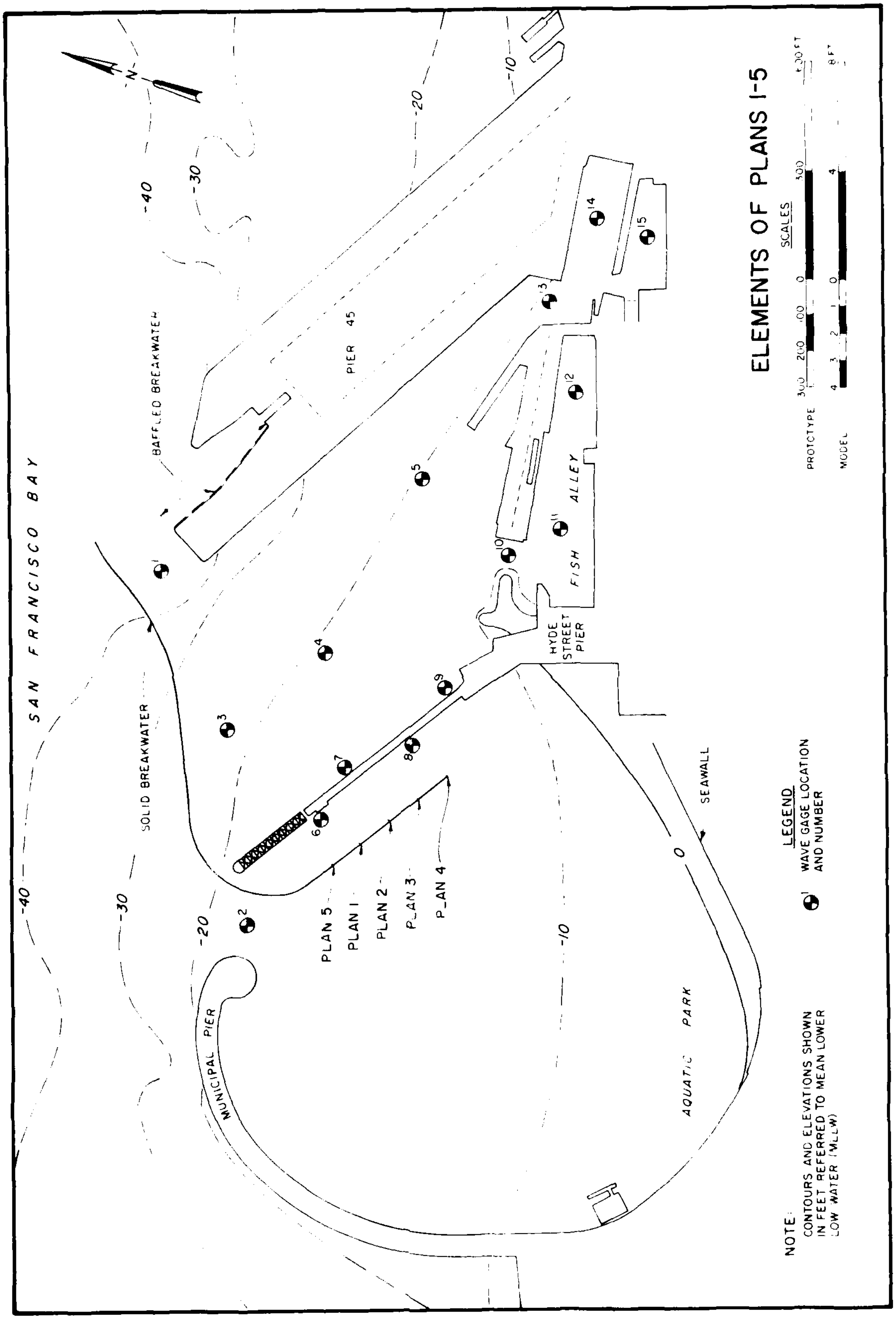

ELEMENTS OF PLANS 1-5
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
SAN FRANCISCO BAY
BAFFLED BREAKWATER
PIER 45
SOLID BREAKWATER
FISH ALLEY
HYDE STREET PIER
SEAWALL
MUNICIPAL PIER
AQUATIC PARK
PLAN 5
PLAN 1
PLAN 2
PLAN 3
PLAN 4
-40
-30
-20
-10
0
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 2

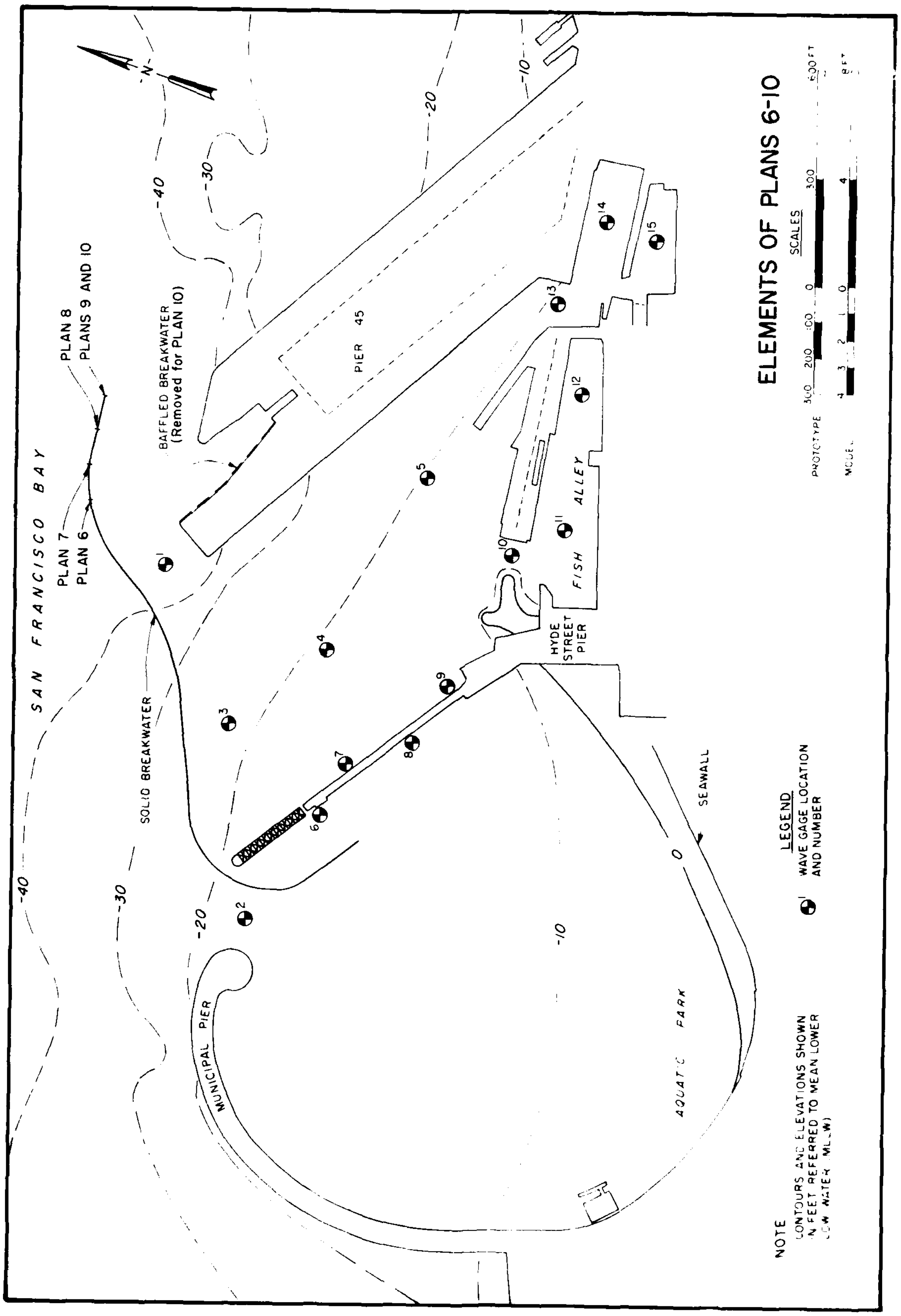

ELEMENTS OF PLANS 6-10
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
N
SAN FRANCISCO BAY
PIER 45
BAFFLED BREAKWATER
(Removed for PLAN 10)
PLAN 8
PLANS 9 AND 10
PLAN 7
PLAN 6
SOLID BREAKWATER
HYDE STREET PIER
FISH ALLEY
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 3

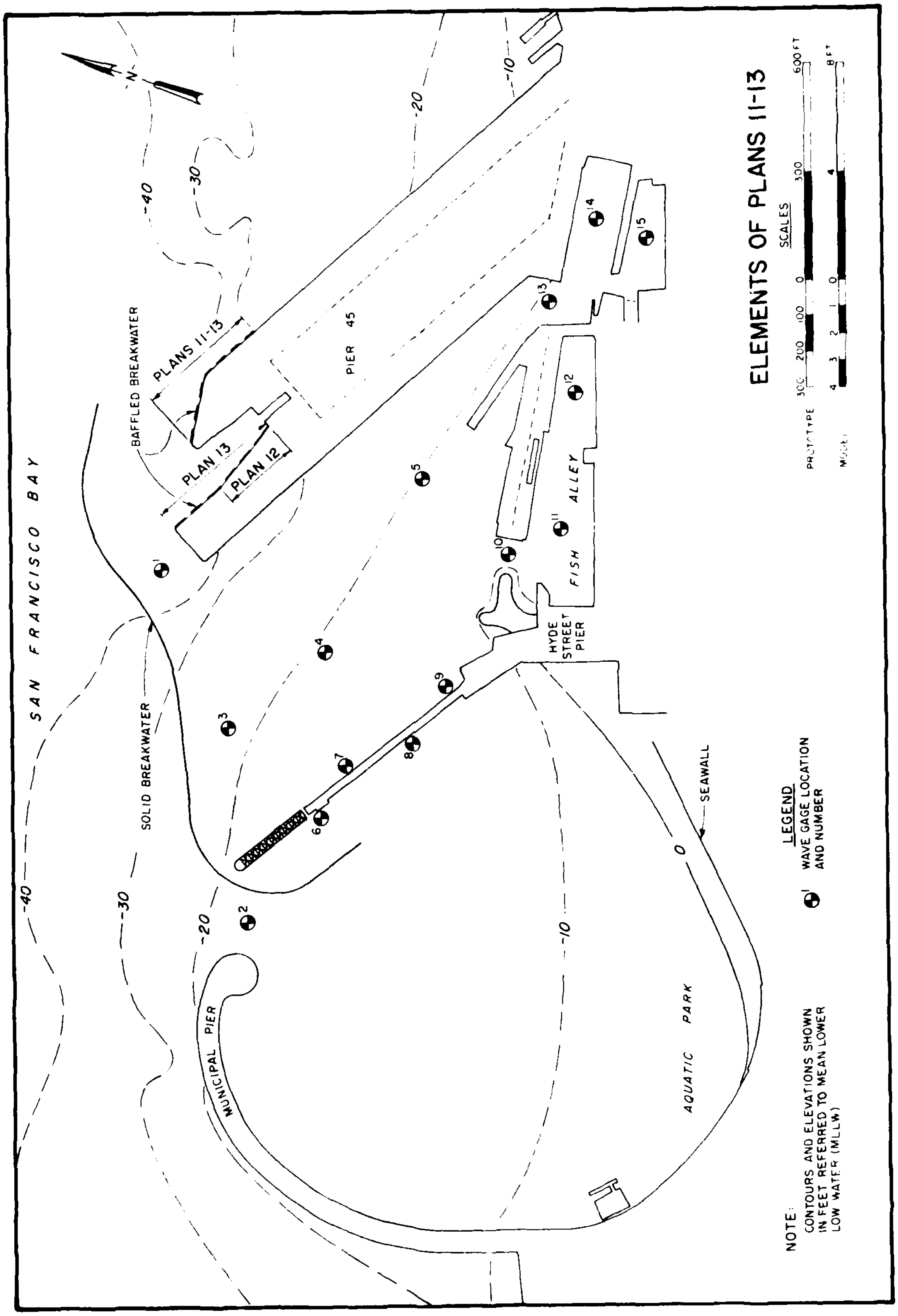
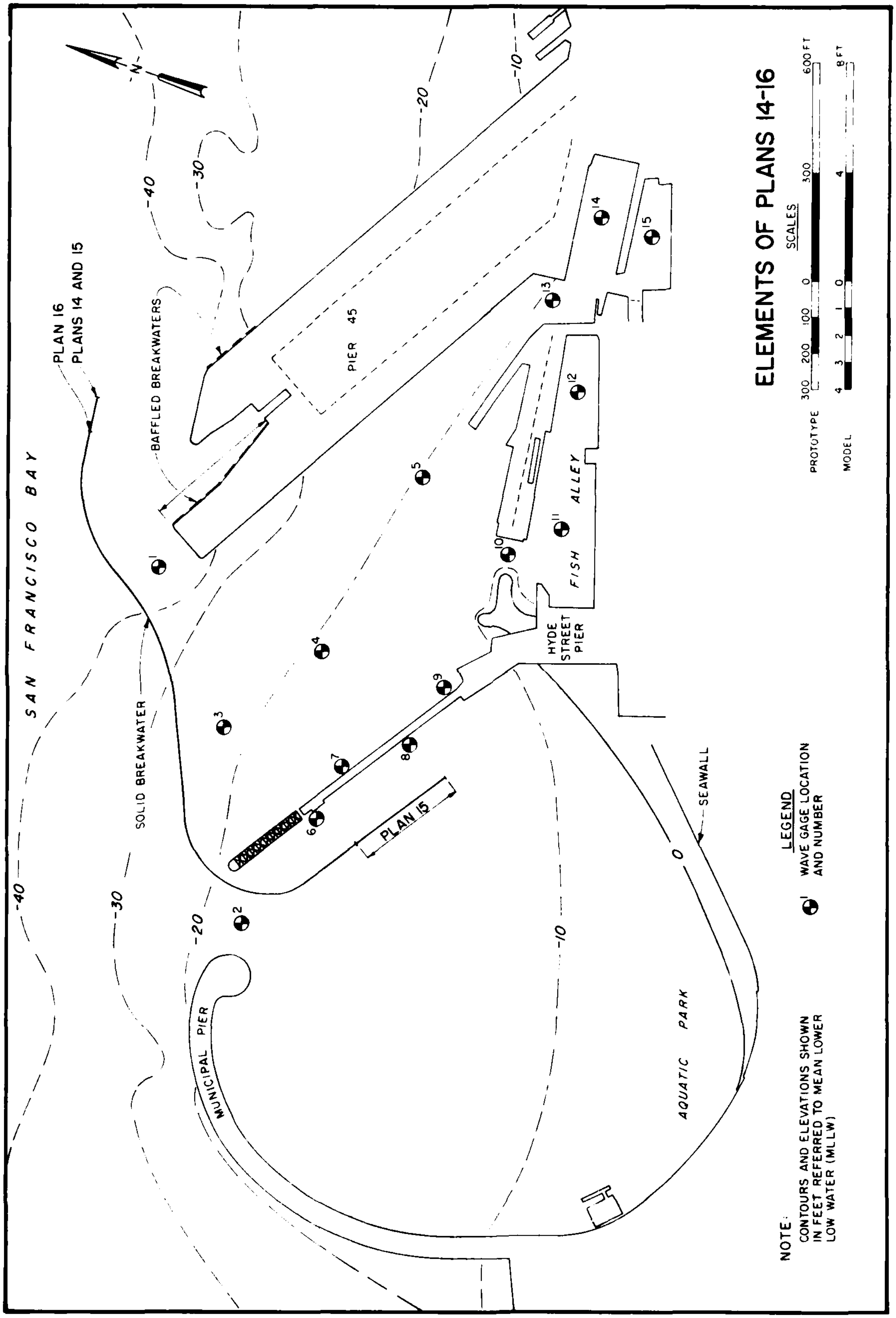

ELEMENTS OF PLANS 11-13
SCALES
PROTOTYPE
MODEL
300 200 100 0 300 600 FT
4 3 2 1 0 4 8 FT
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
N
SAN FRANCISCO BAY
BAFFLED BREAKWATER
PLANS 11-13
PLAN 13
PLAN 12
PIER 45
FISH ALLEY
HYDE STREET PIER
SOLID BREAKWATER
SEAWALL
MUNICIPAL PIER
AQUATIC PARK
-40
-30
-20
-10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

PLATE 4


ELEMENTS OF PLANS 14-16
SCALES
300 200 100 0 300 600 FT
PROTOTYPE
4 3 2 1 0 4 8 FT
MODEL
N
SAN FRANCISCO BAY
PLAN 16
PLANS 14 AND 15
BAFFLED BREAKWATERS
SOLID BREAKWATER
PIER 45
FISH ALLEY
HYDE STREET PIER
PLAN 15
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

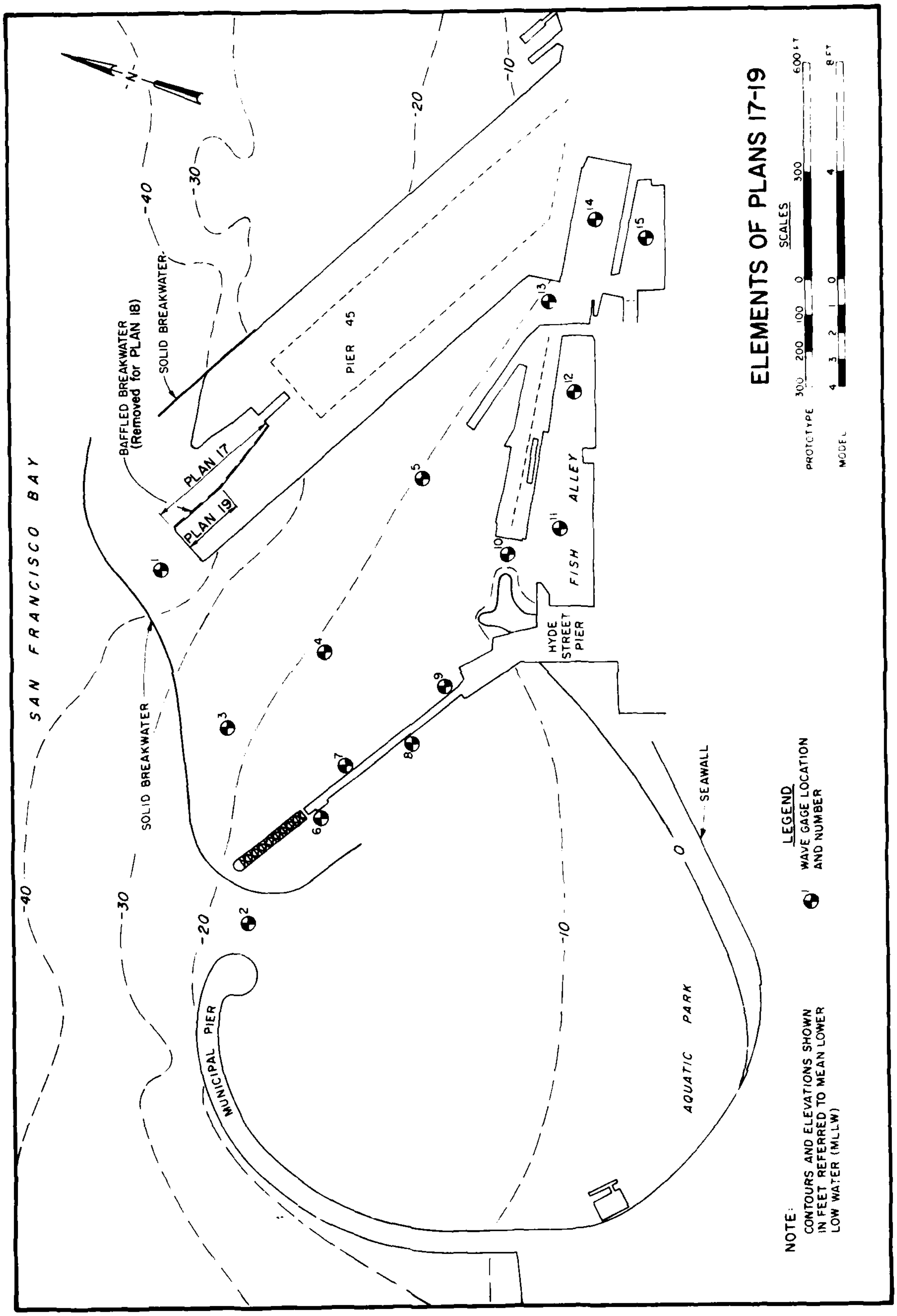
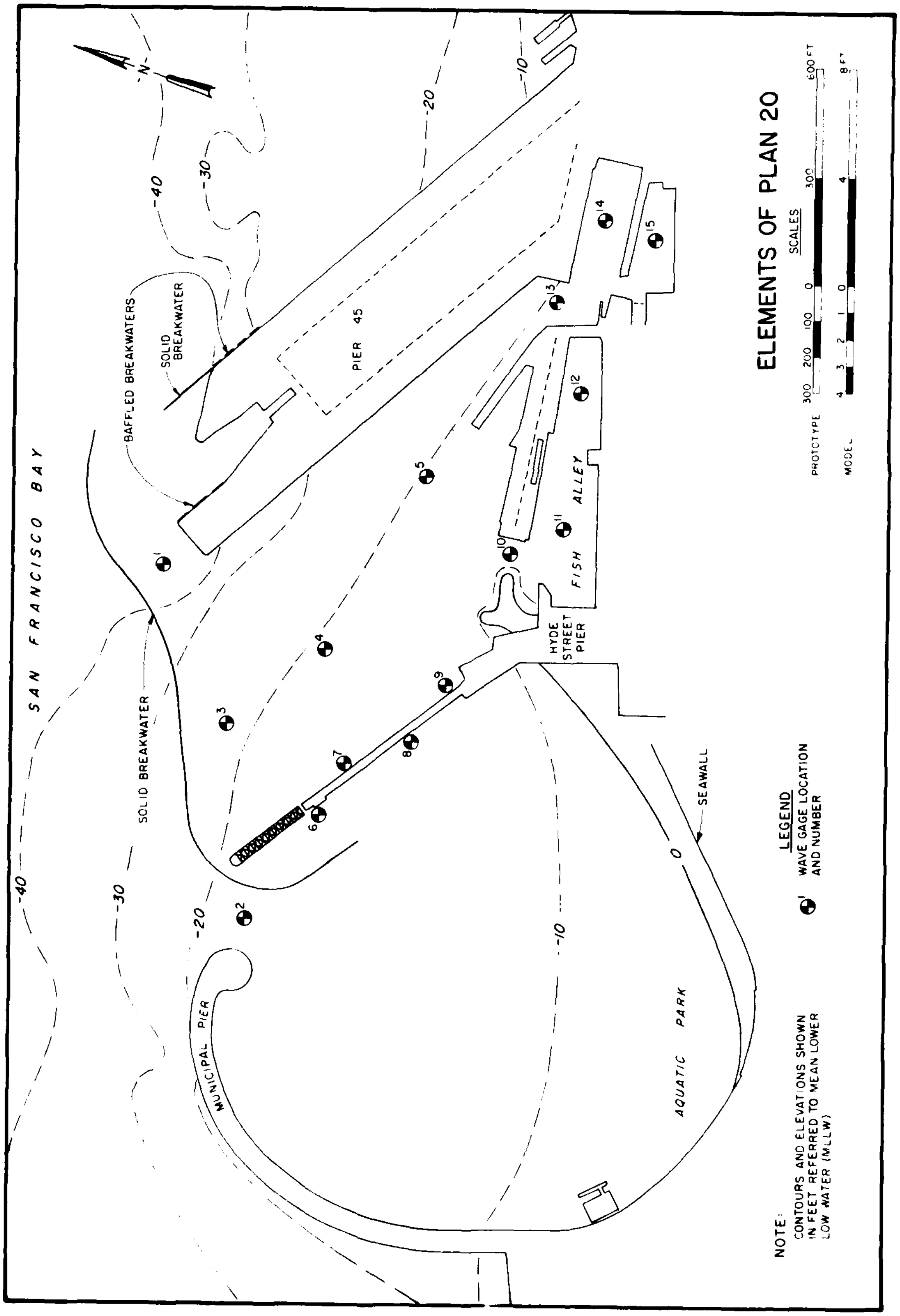
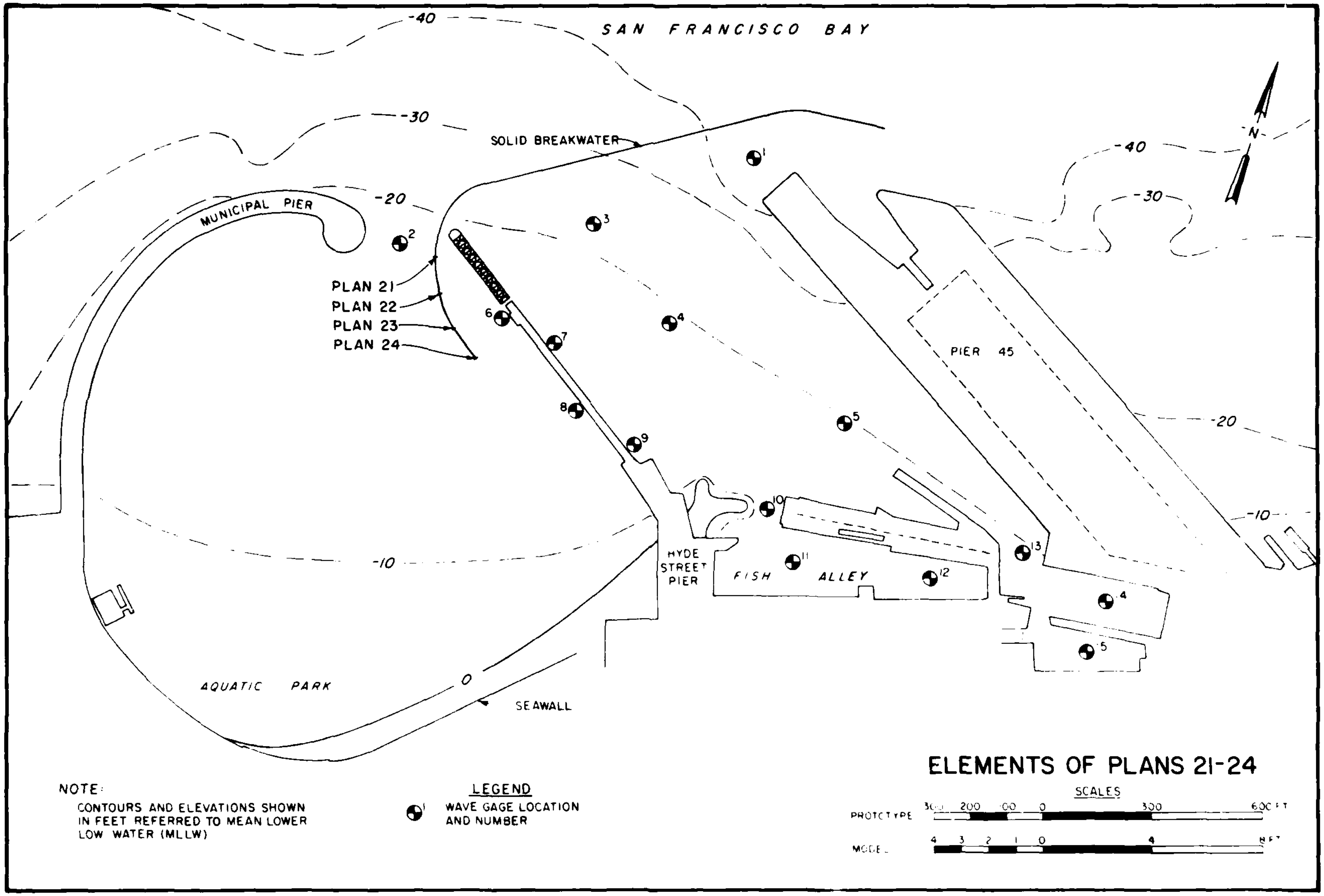

ELEMENTS OF PLANS 17-19
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SAN FRANCISCO BAY
N
PIER 45
FISH ALLEY
HYDE STREET PIER
SOLID BREAKWATER
BAFFLED BREAKWATER (Removed for PLAN 18)
PLAN 17
PLAN 19
MUNICIPAL PIER
AQUATIC PARK
SEAWALL

PLATE 6



ELEMENTS OF PLAN 20



ELEMENTS OF PLANS 21-24

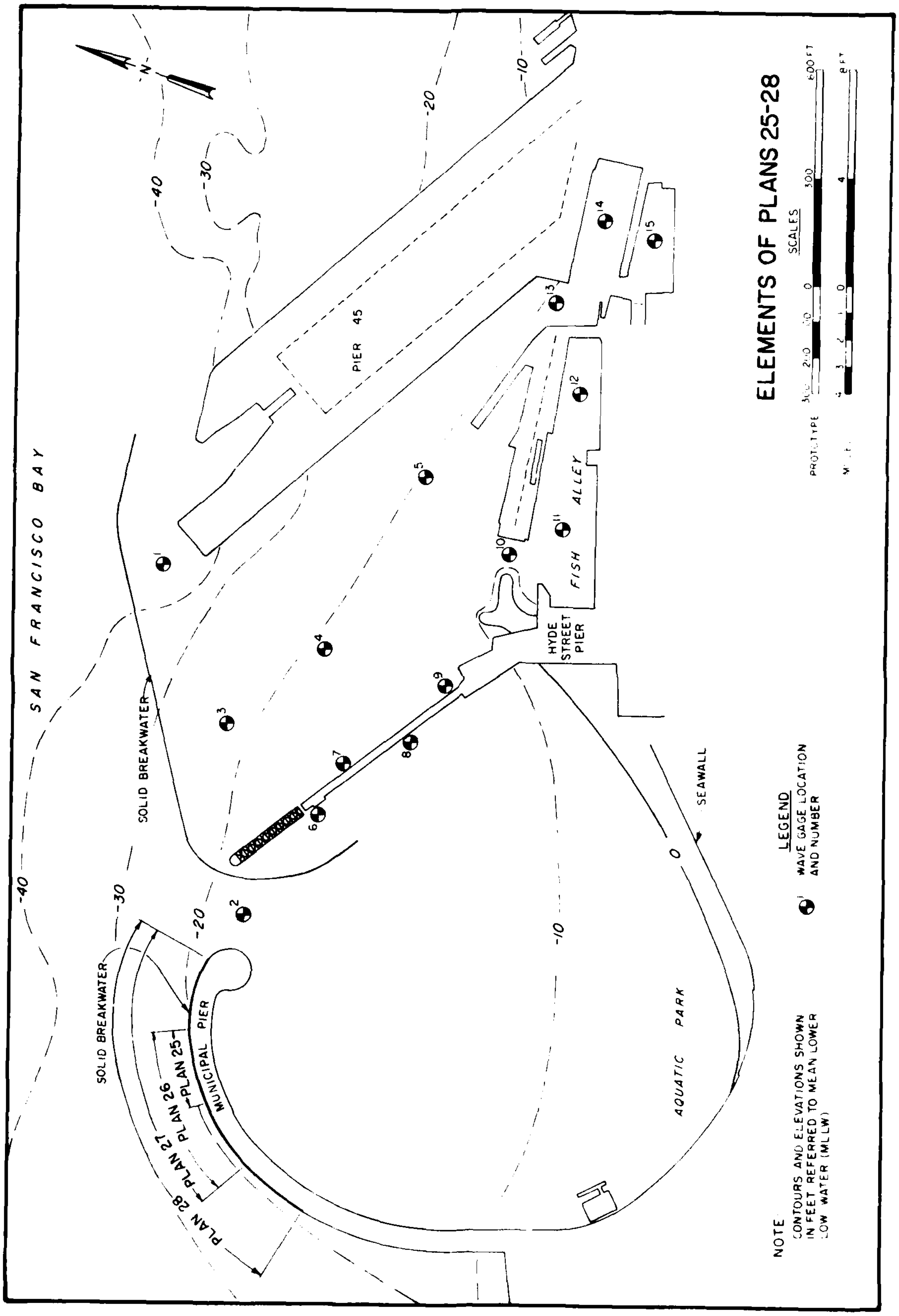
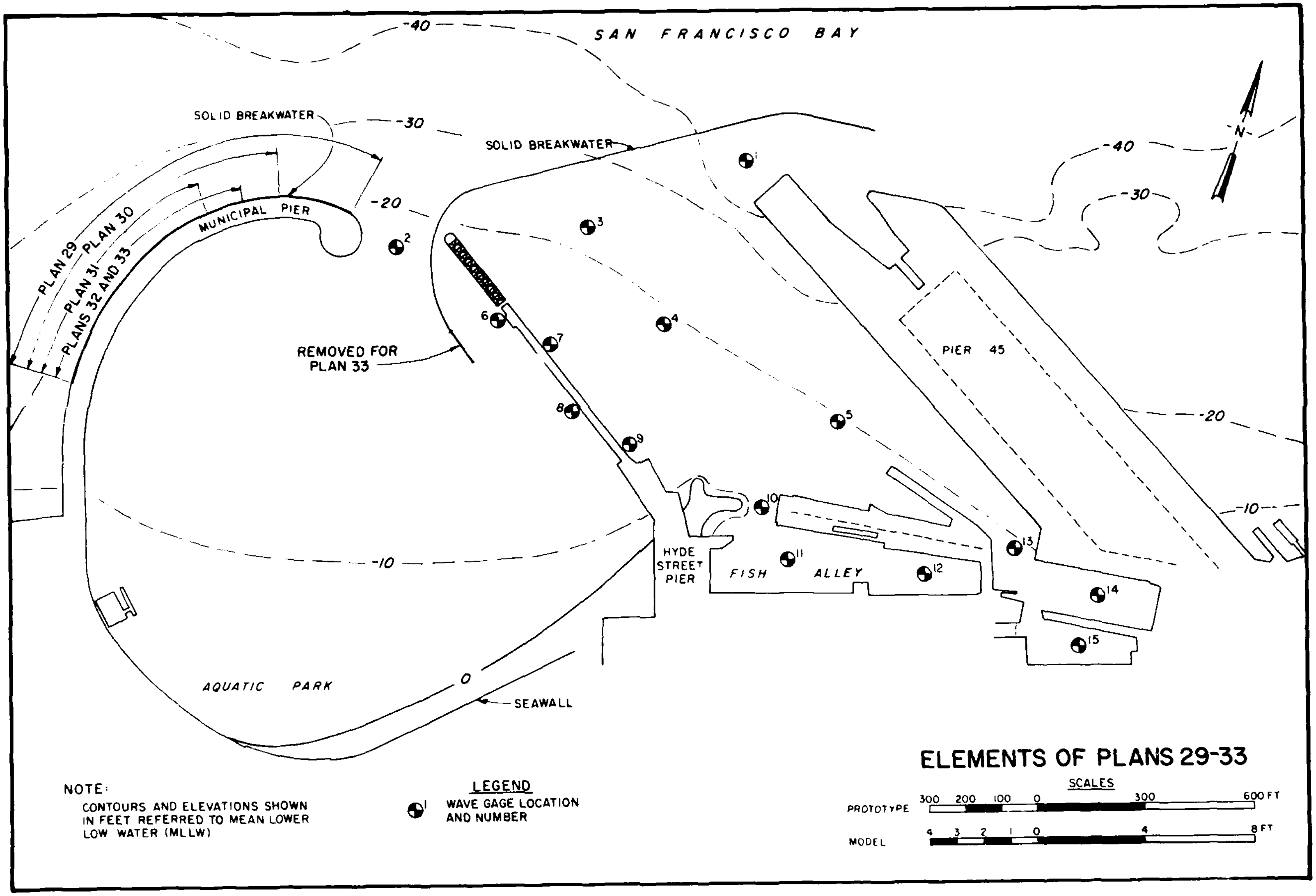

ELEMENTS OF PLANS 25-28
SCALES
PROTOTYPE
N
SAN FRANCISCO BAY
SOLID BREAKWATER
SOLID BREAKWATER
PIER 45
FISH ALLEY
HYDE STREET PIER
SEAWALL
AQUATIC PARK
MUNICIPAL PIER
PLAN 25
PLAN 26
PLAN 27
PLAN 28
-40
-30
-20
-10
0
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 9


SAN FRANCISCO BAY
-40
-30
-20
-10
0
N
SOLID BREAKWATER
SOLID BREAKWATER
MUNICIPAL PIER
PLAN 29
PLAN 30
PLAN 31
PLANS 32 AND 33
REMOVED FOR PLAN 33
PIER 45
HYDE STREET PIER
FISH ALLEY
AQUATIC PARK
SEAWALL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
ELEMENTS OF PLANS 29-33
SCALES
PROTOTYPE
300 200 100 0 300 600 FT
MODEL
4 3 2 1 0 4 8 FT

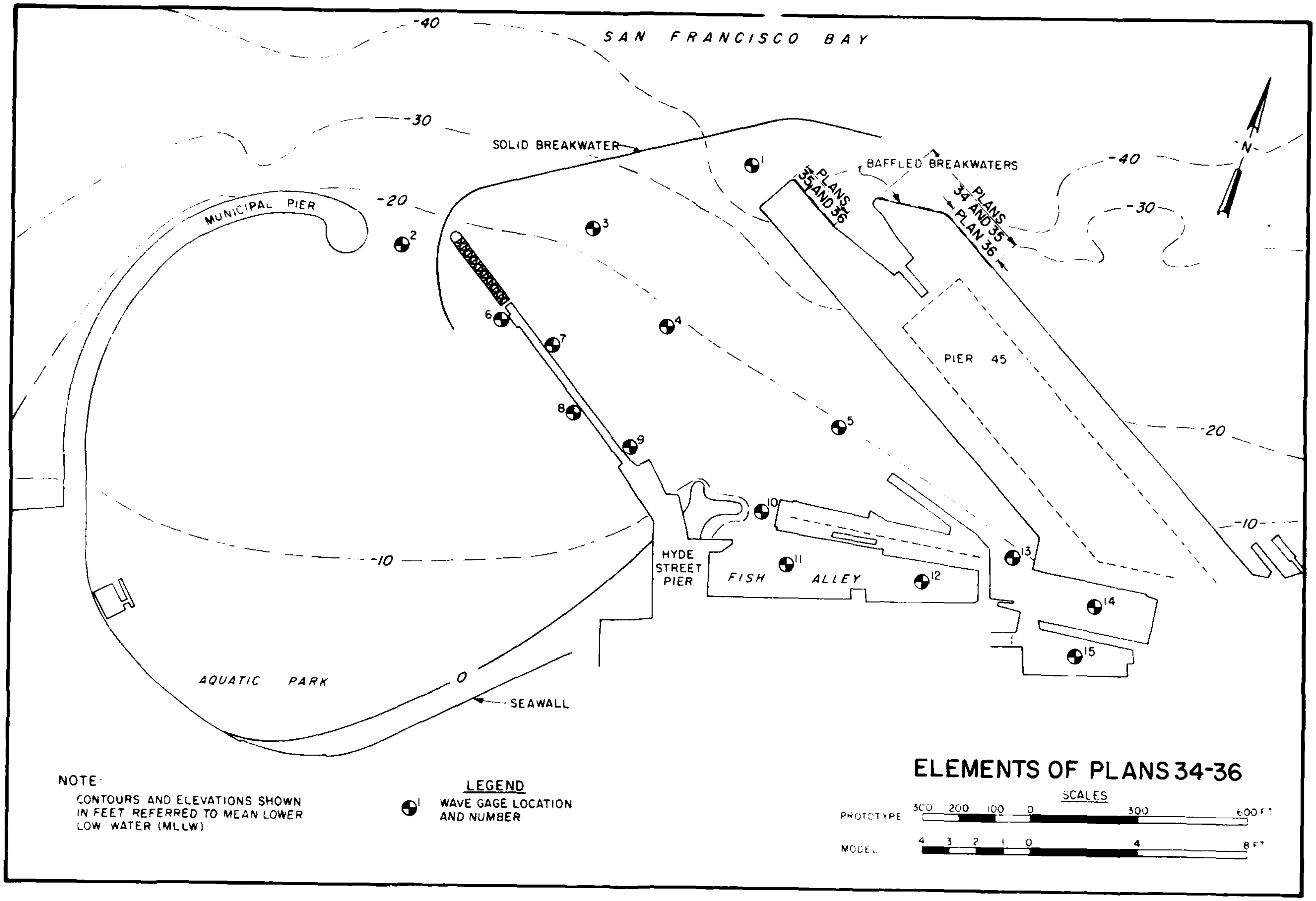
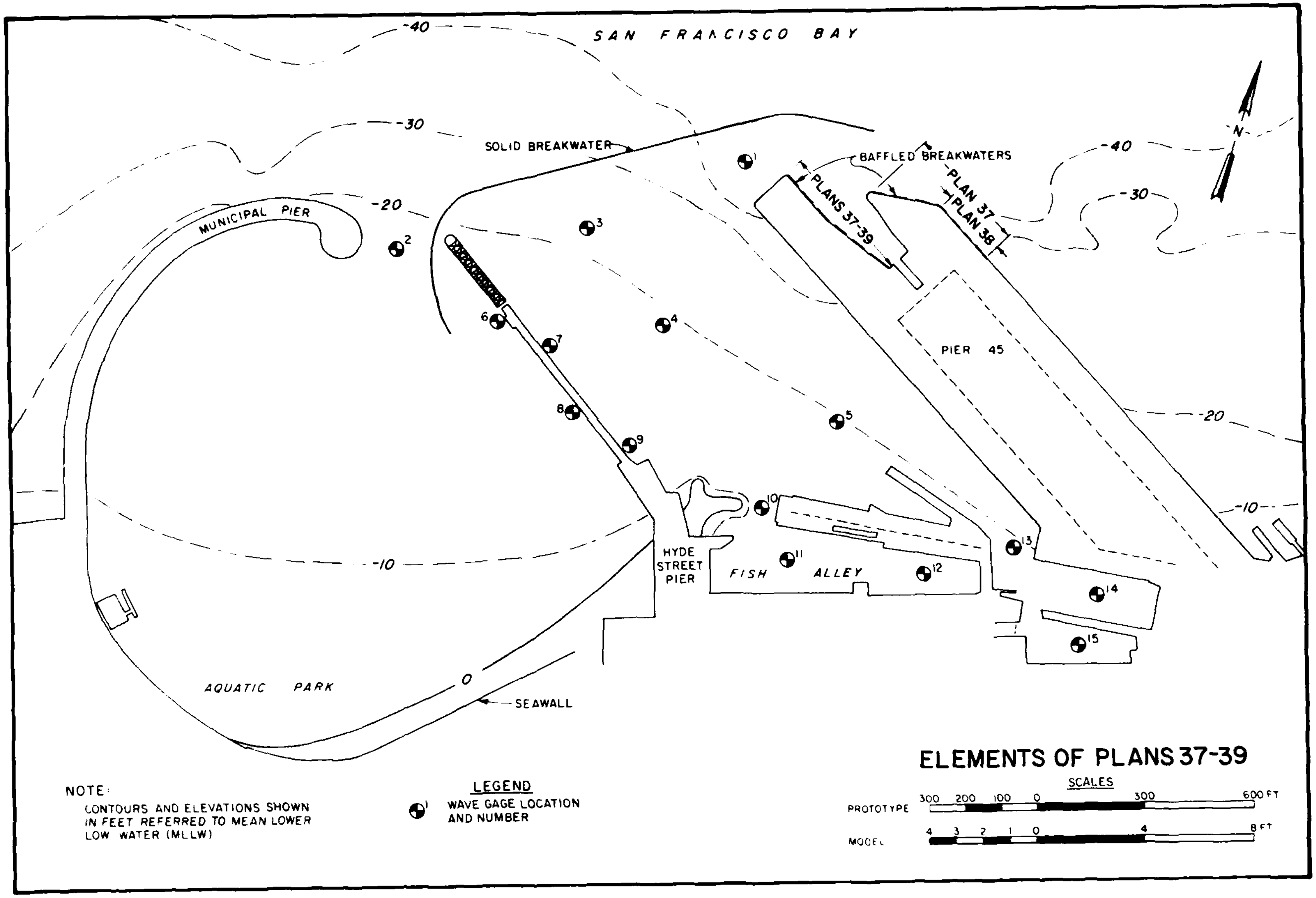

SAN FRANCISCO BAY
-40
-30
-20
-10
0
SOLID BREAKWATER
BAFFLED BREAKWATERS
PLANS 35 AND 36
PLANS 34 AND 35
PLAN 36
N
MUNICIPAL PIER
PIER 45
HYDE STREET PIER
FISH ALLEY
AQUATIC PARK
SEAWALL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
ELEMENTS OF PLANS 34-36
SCALES
PROTOTYPE
300 200 100 0 300 600 FT
MODEL
4 3 2 1 0 4 8 FT

PLATE 11



ELEMENTS OF PLANS 37-39

PLATE 12

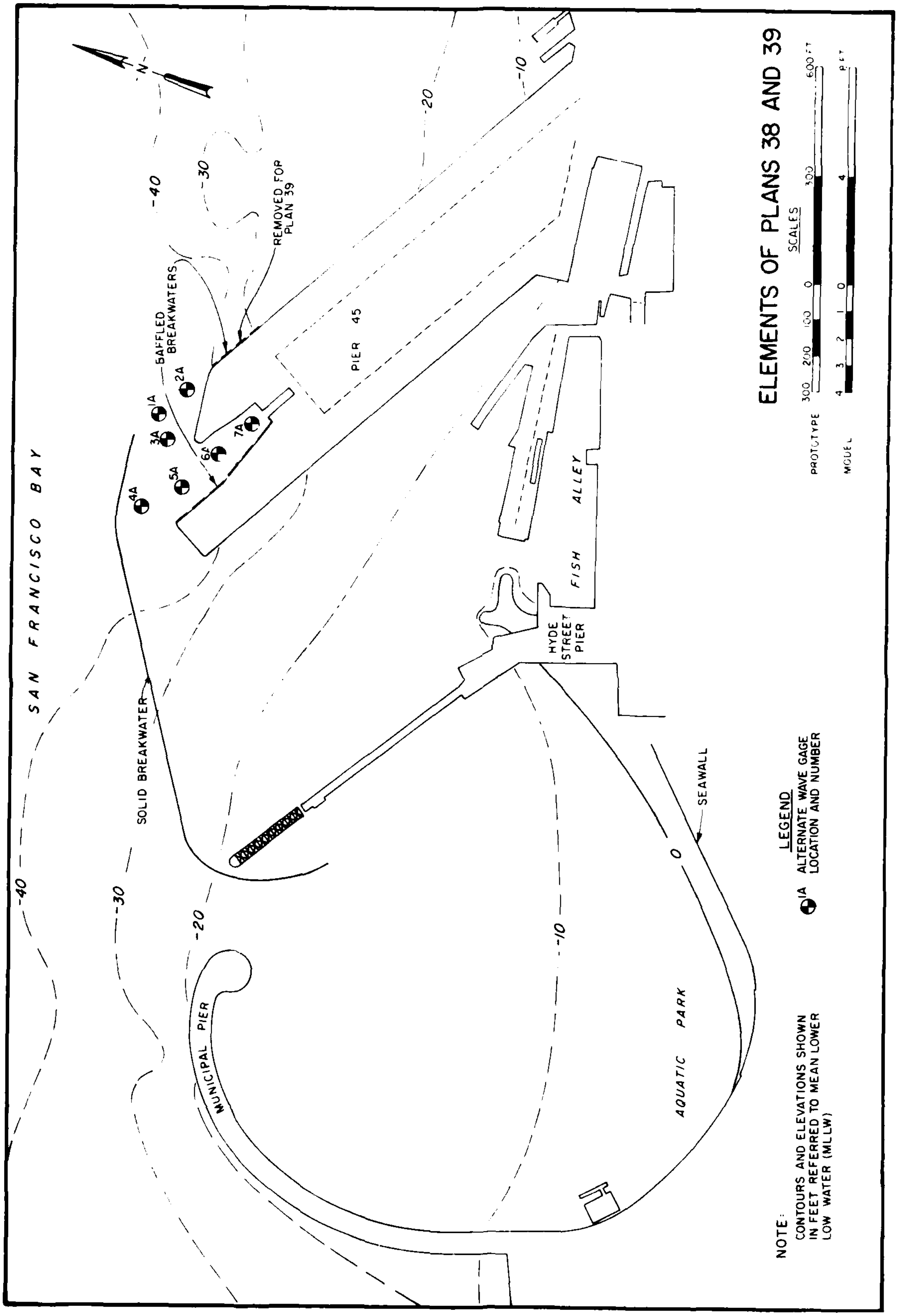

ELEMENTS OF PLANS 38 AND 39
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
N
SAN FRANCISCO BAY
BAFFLED BREAKWATERS
REMOVED FOR PLAN 39
PIER 45
FISH ALLEY
HYDE STREET PIER
SOLID BREAKWATER
SEAWALL
MUNICIPAL PIER
AQUATIC PARK
1A
2A
3A
4A
5A
6A
7A
-40
-30
-20
-10
0
LEGEND
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 13

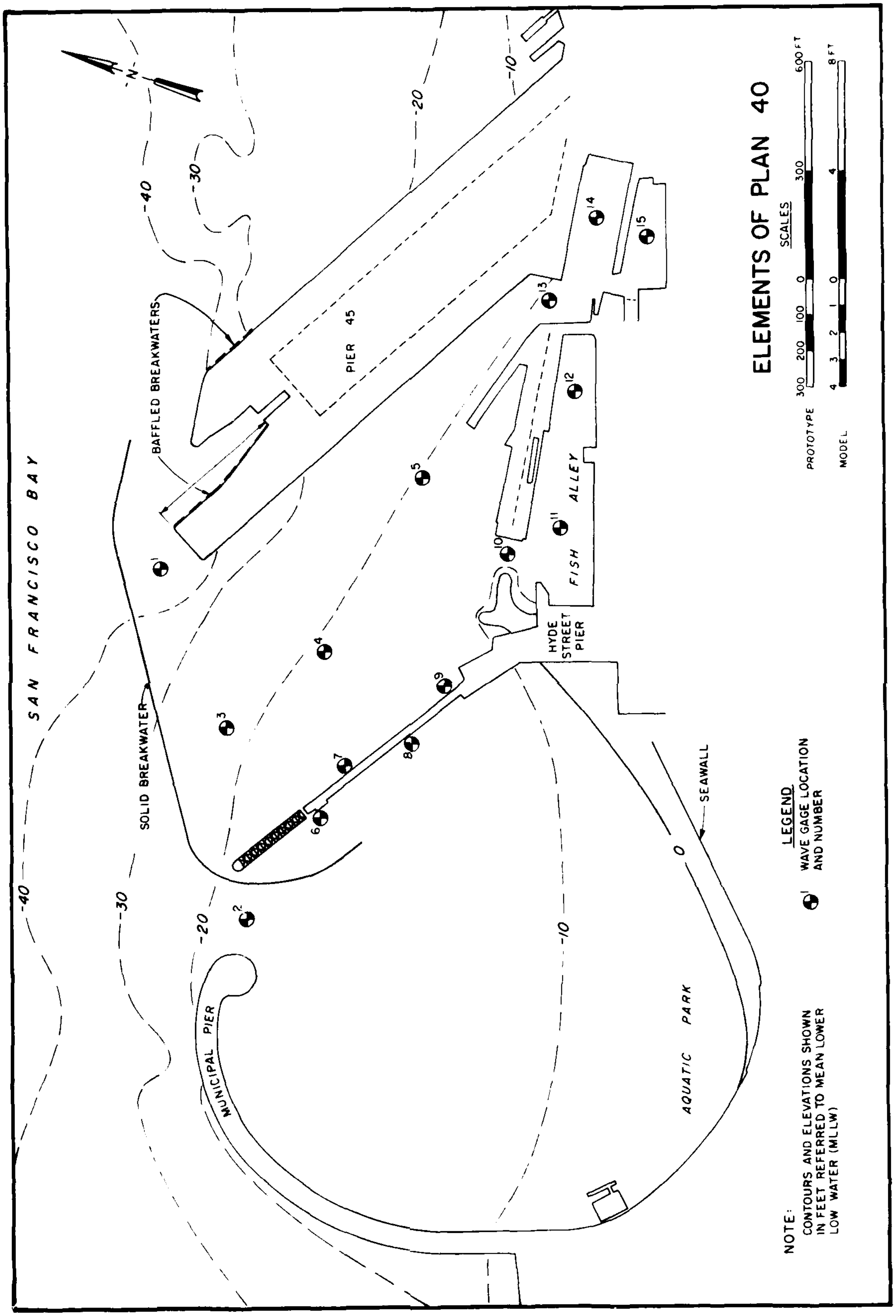
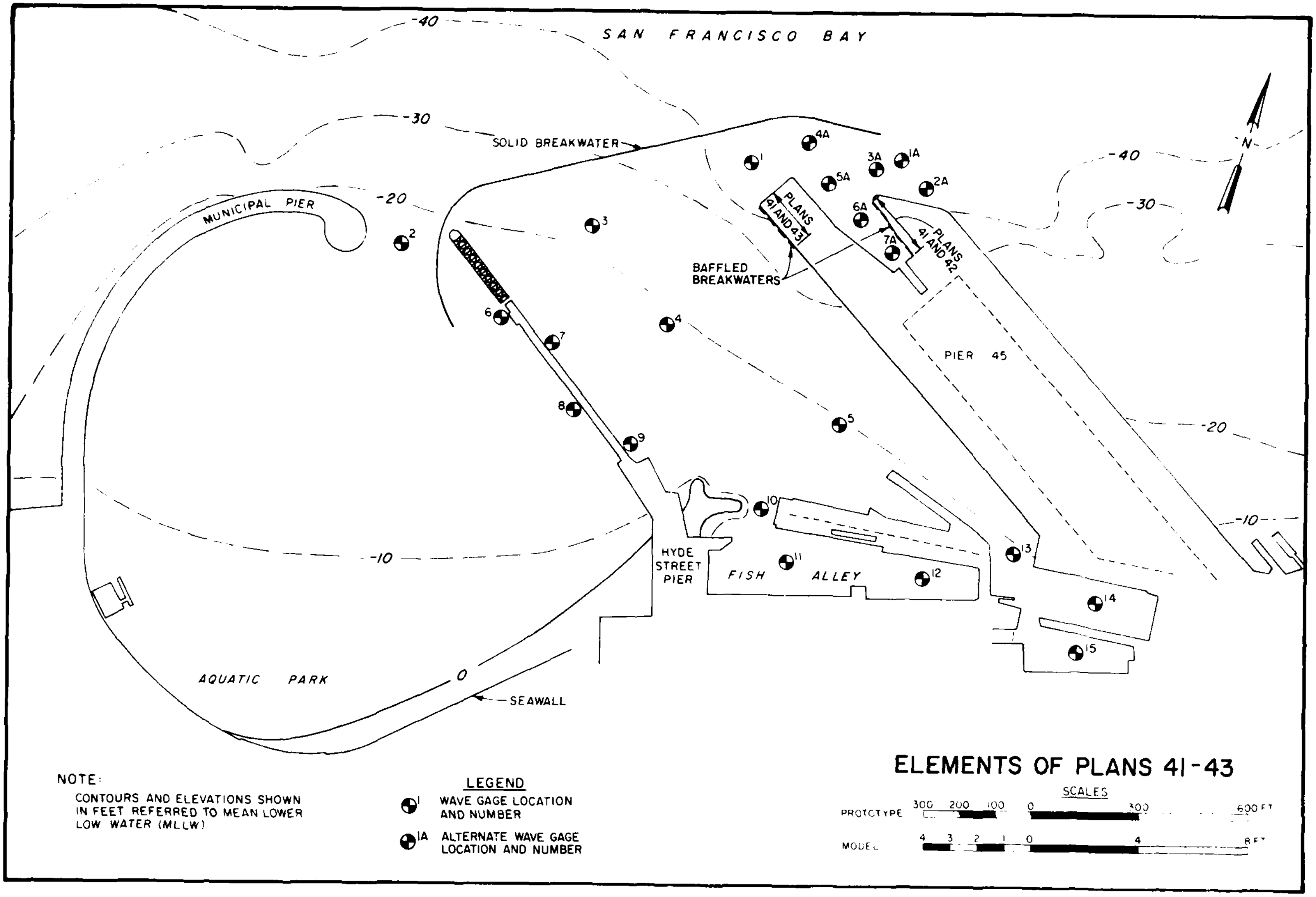
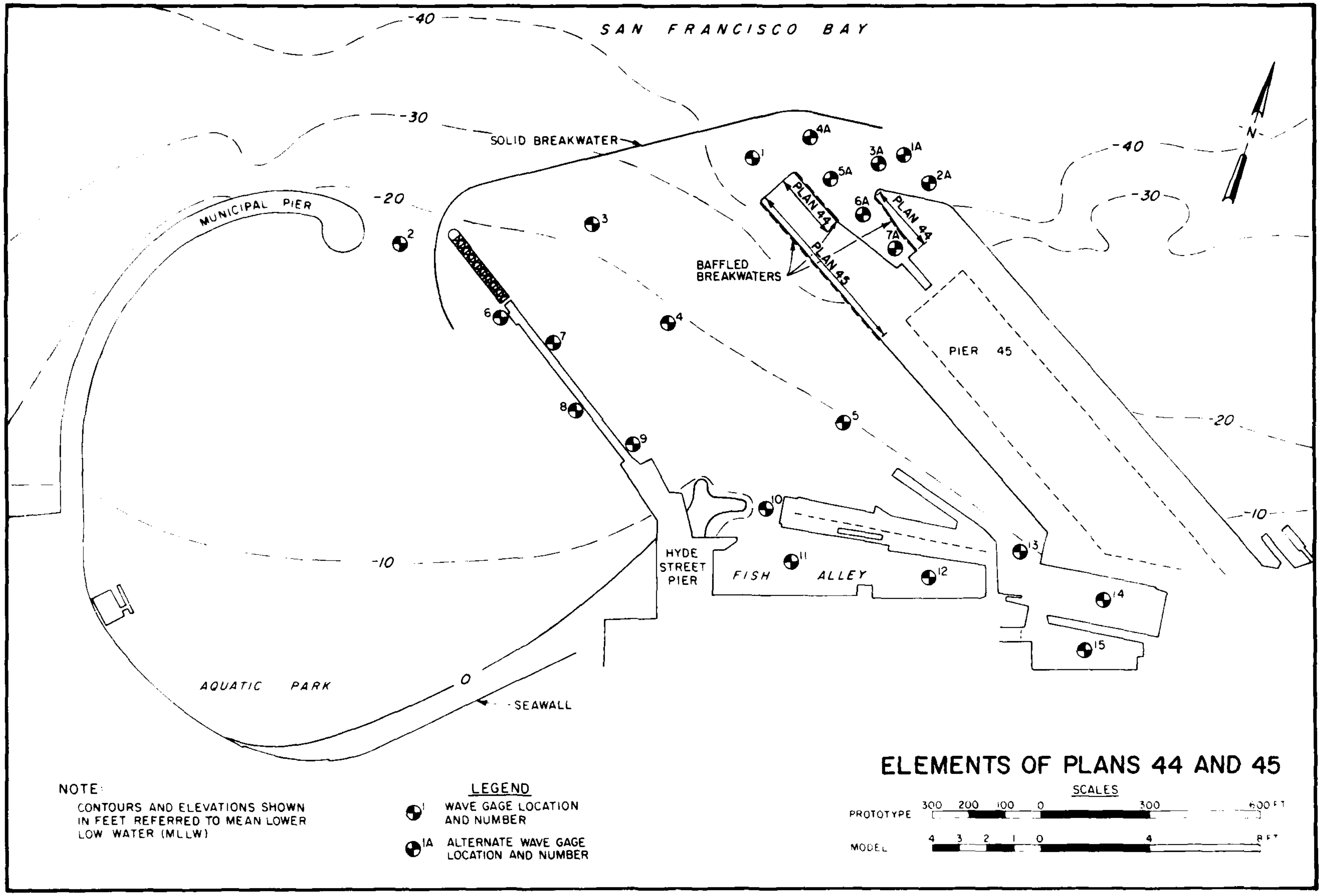

ELEMENTS OF PLAN 40
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
LEGEND
WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SAN FRANCISCO BAY
N
BAFFLED BREAKWATERS
PIER 45
SOLID BREAKWATER
HYDE STREET PIER
FISH ALLEY
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0

PLATE 14

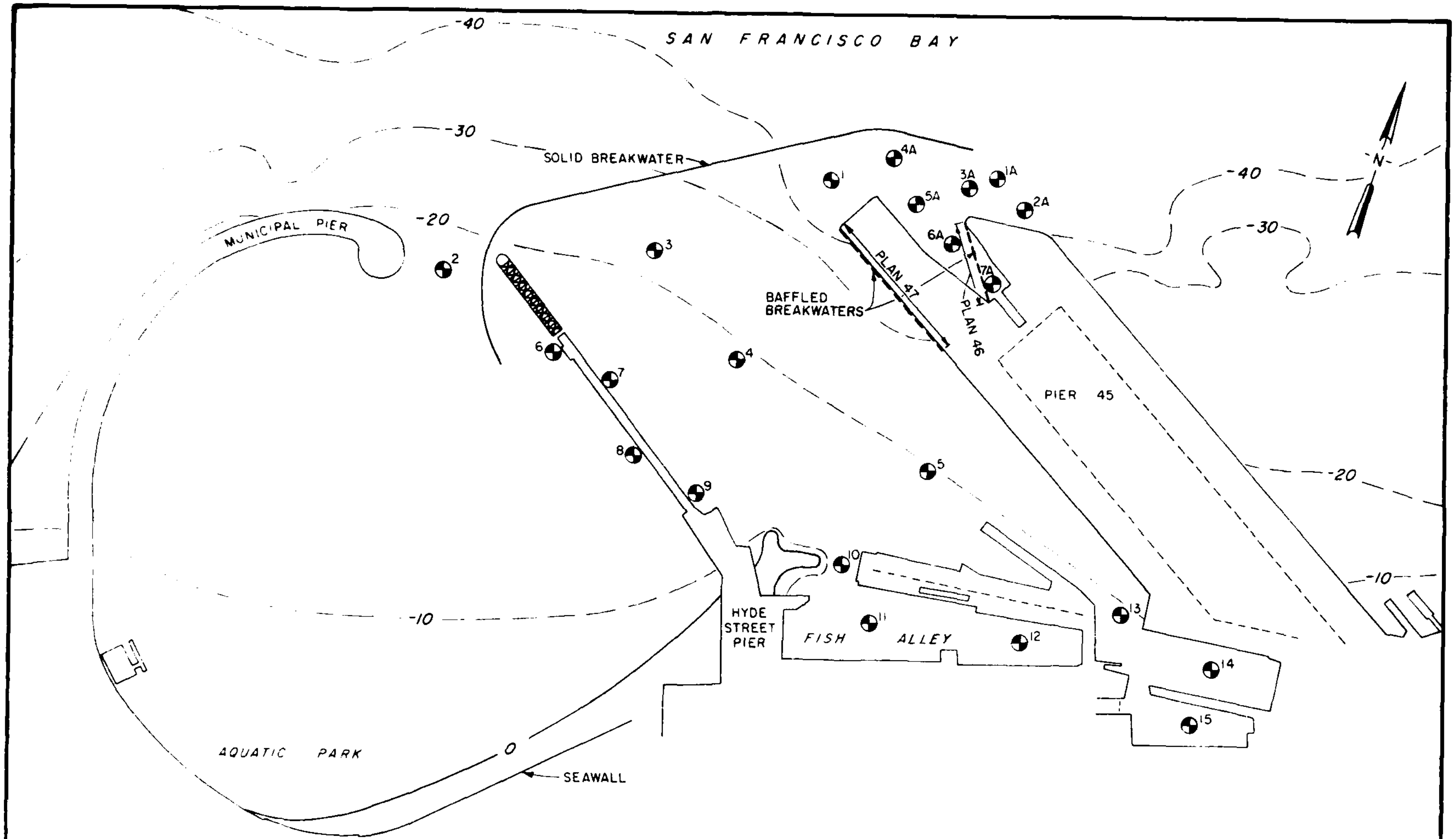


ELEMENTS OF PLANS 41-43



ELEMENTS OF PLANS 44 AND 45

PLATE 16



ELEMENTS OF PLANS 46 AND 47

SCALES

PROTOTYPE 300 200 100 0 300 600 FT

MODEL 4 3 2 1 0 4 8 FT

LEGEND

WAVE GAGE LOCATION AND NUMBER

ALTERNATE WAVE GAGE LOCATION AND NUMBER

NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

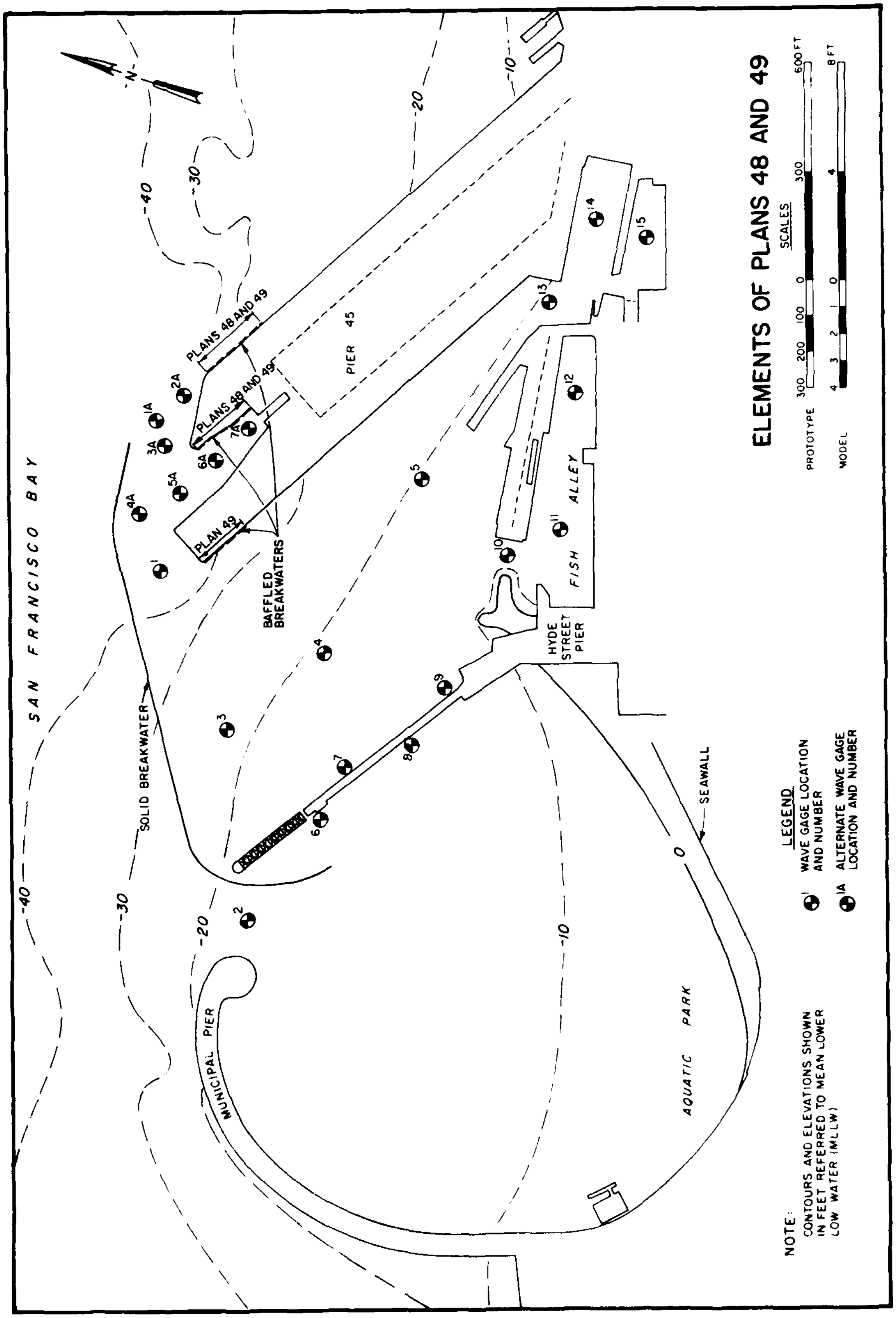

ELEMENTS OF PLANS 48 AND 49
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
SAN FRANCISCO BAY
N
SOLID BREAKWATER
BAFFLED BREAKWATERS
PLANS 48 AND 49
PLANS 48 AND 49
PLAN 49
PIER 45
FISH ALLEY
HYDE STREET PIER
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 18

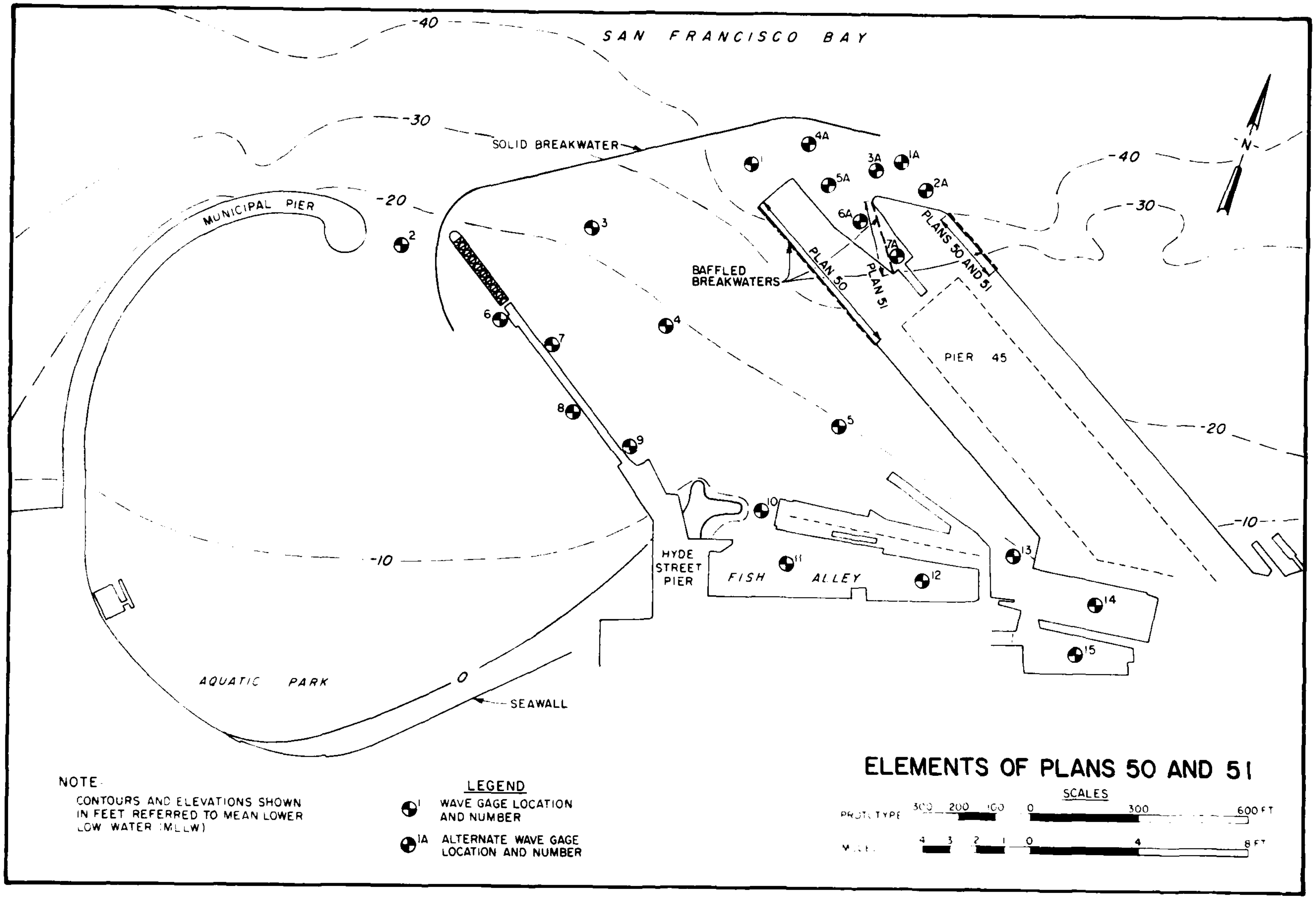
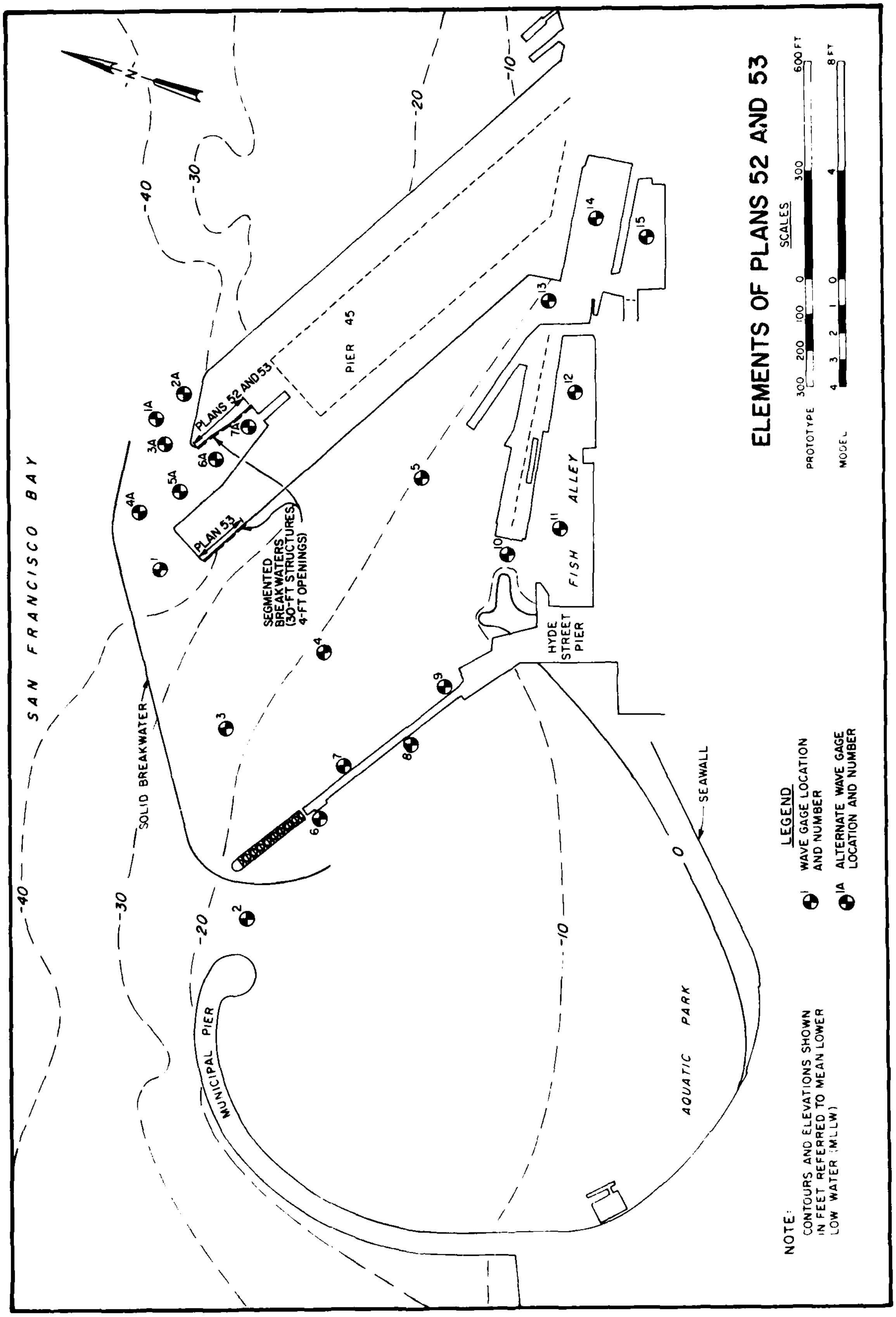
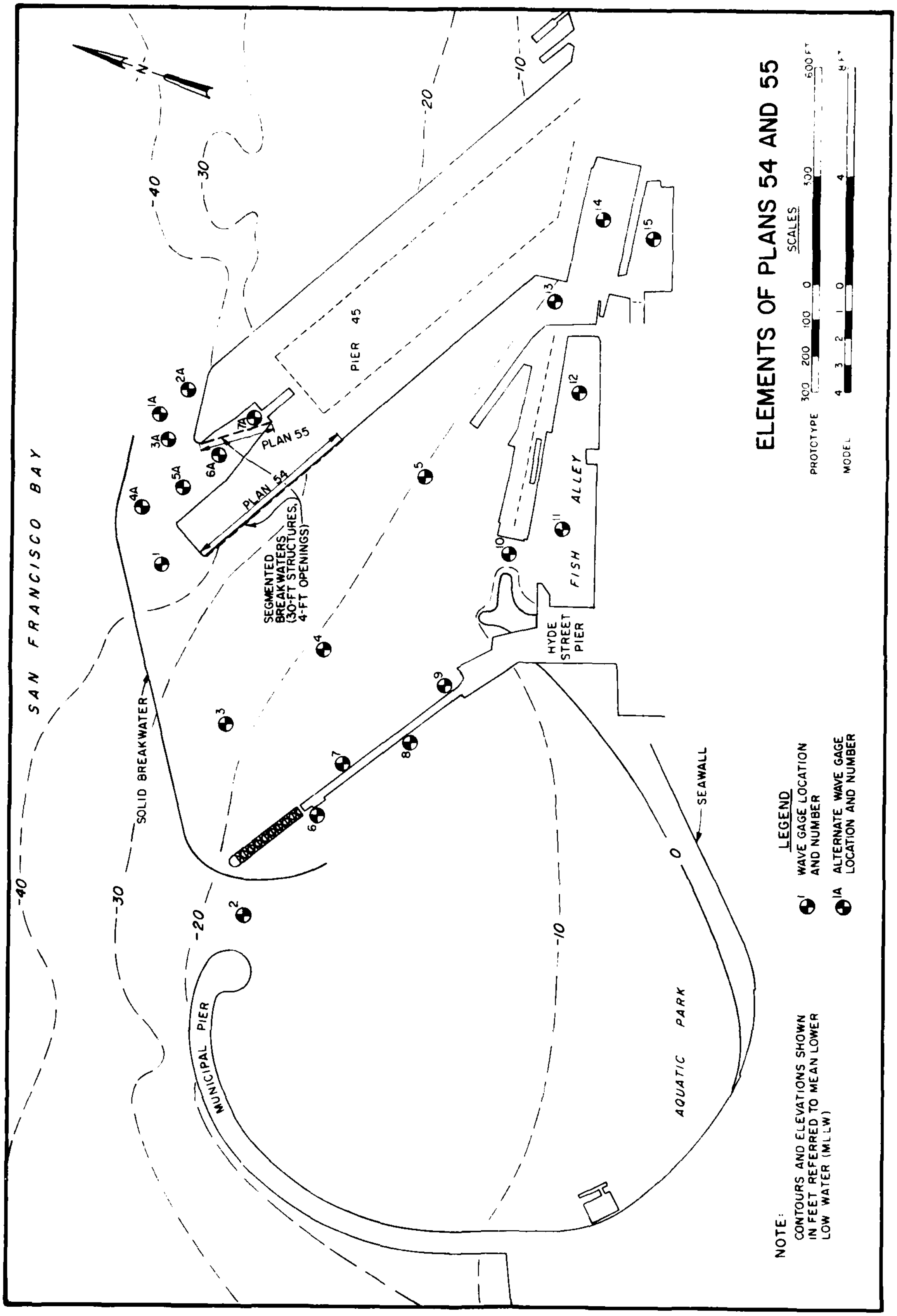
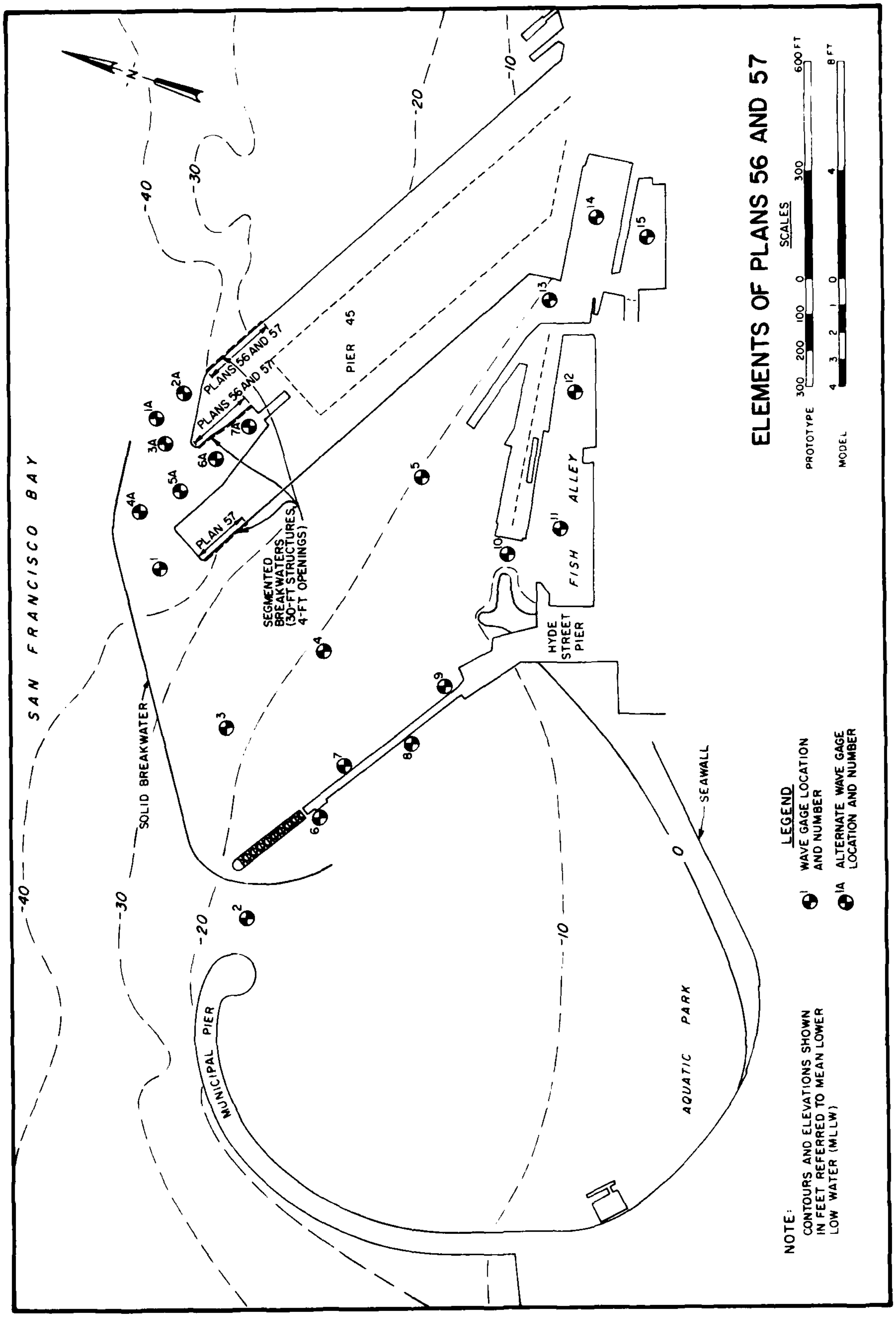

SAN FRANCISCO BAY
N
-40
-30
-20
-10
0
SOLID BREAKWATER
MUNICIPAL PIER
BAFFLED BREAKWATERS
PLAN 50
PLAN 51
PLANS 50 AND 51
PIER 45
HYDE STREET PIER
FISH ALLEY
AQUATIC PARK
SEAWALL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1A
2A
3A
4A
5A
6A
7A
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
ELEMENTS OF PLANS 50 AND 51
SCALES
300 200 100 0 300 600 FT
4 3 2 1 0 4 8 FT

PLATE 19

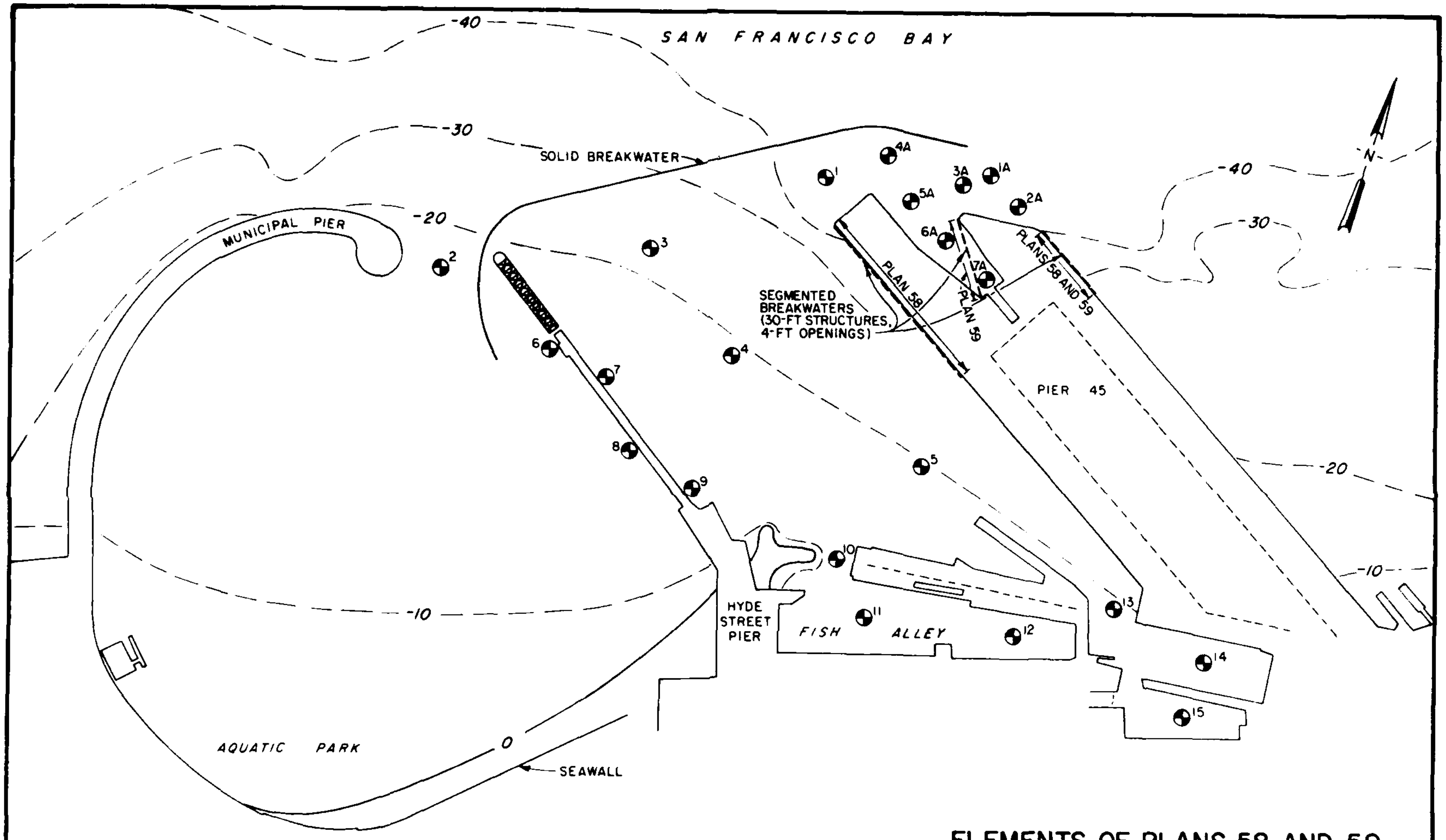


ELEMENTS OF PLANS 52 AND 53


ELEMENTS OF PLANS 54 AND 55
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
N
SAN FRANCISCO BAY
PIER 45
PLAN 55
PLAN 54
SEGMENTED BREAKWATERS (30-FT STRUCTURES, 4-FT OPENINGS)
SOLID BREAKWATER
HYDE STREET PIER
FISH ALLEY
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)



ELEMENTS OF PLANS 56 AND 57



ELEMENTS OF PLANS 58 AND 59

SCALES

PROTOTYPE 300 200 100 0 300 600 FT

MODEL 4 3 2 1 0 4 8 FT

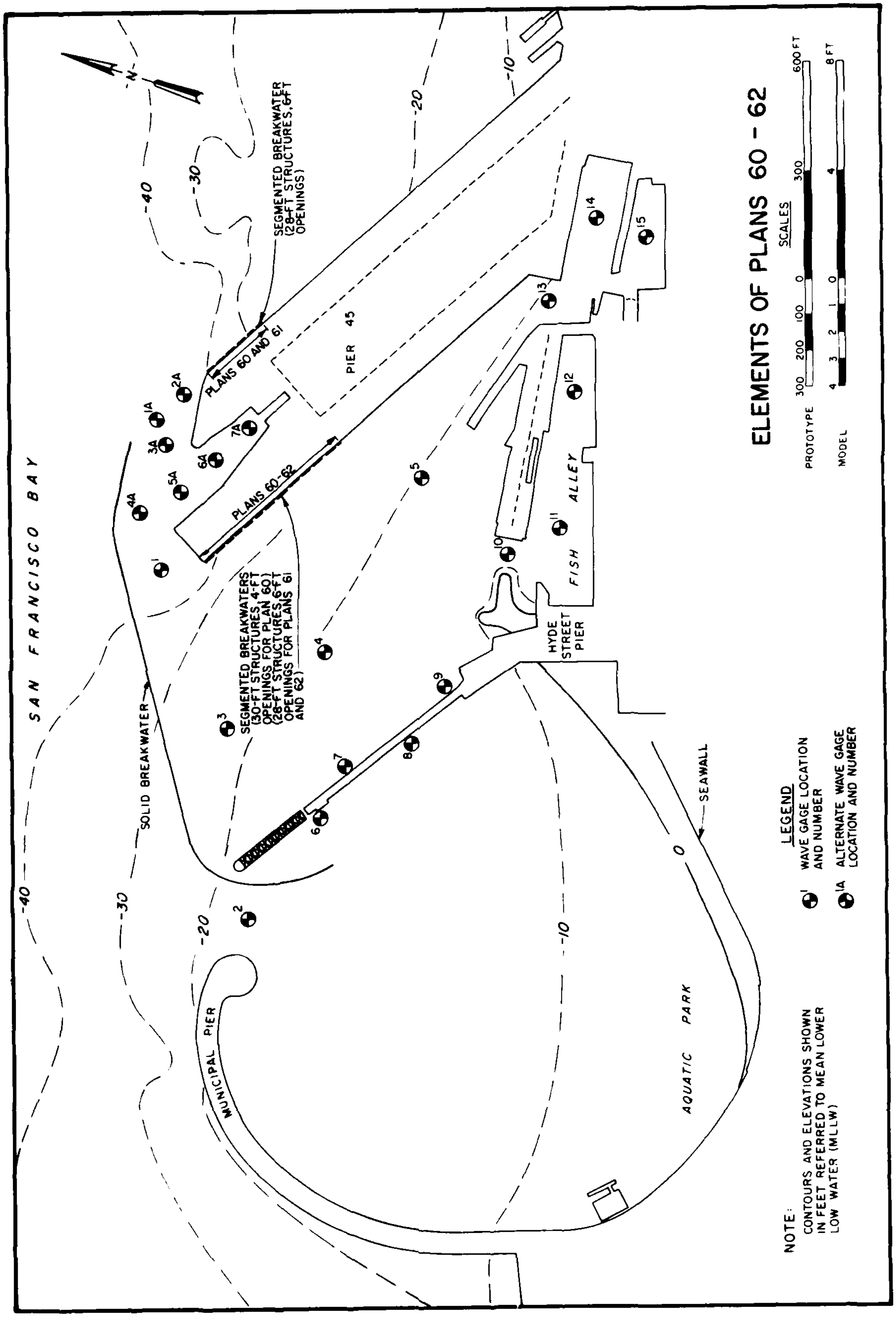
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

LEGEND

1 WAVE GAGE LOCATION AND NUMBER

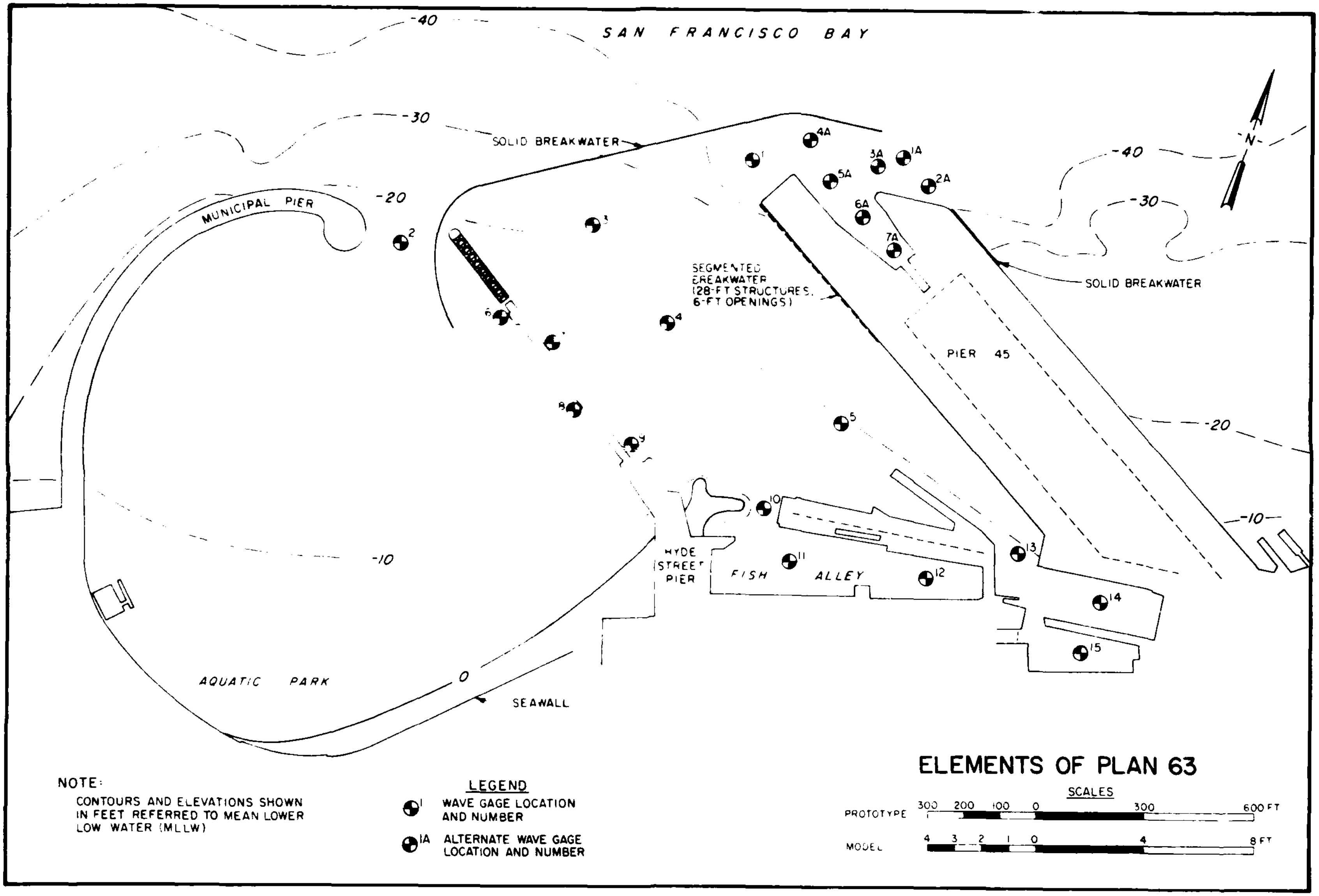
1A ALTERNATE WAVE GAGE LOCATION AND NUMBER

PLATE 23



ELEMENTS OF PLANS 60 - 62
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
SAN FRANCISCO BAY
SOLID BREAKWATER
SEGMENTED BREAKWATER (28-FT STRUCTURES, 6-FT OPENINGS)
SEGMENTED BREAKWATERS (30-FT STRUCTURES, 4-FT OPENINGS FOR PLAN 60) (28-FT STRUCTURES, 6-FT OPENINGS FOR PLANS 61 AND 62)
PLANS 60 AND 61
PLANS 60-62
PIER 45
FISH ALLEY
HYDE STREET PIER
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
N
-40
-30
-20
-10
0
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 24



ELEMENTS OF PLAN 63

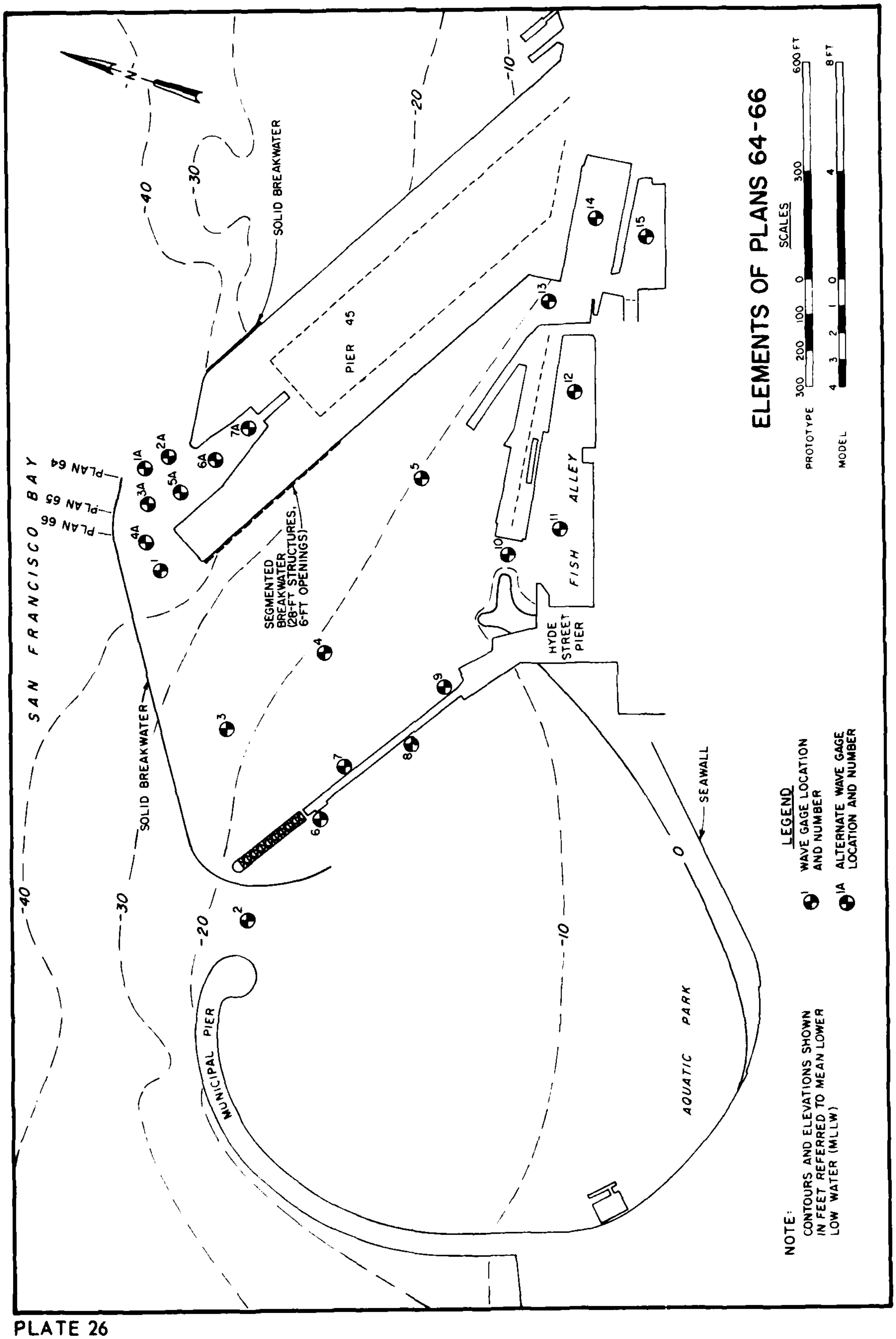
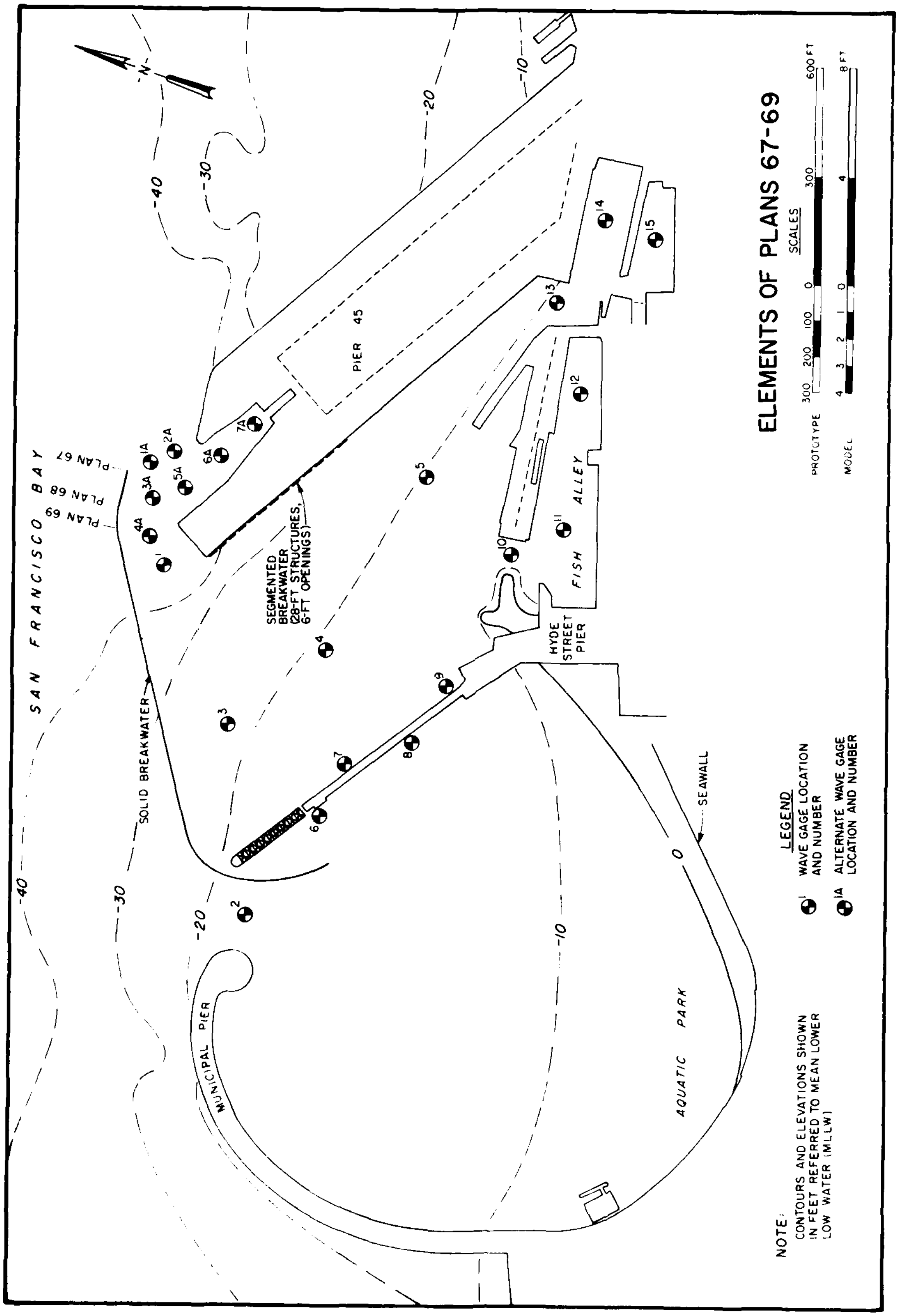

ELEMENTS OF PLANS 64-66
SCALES
PROTOTYPE
300 200 100 0 300 600 FT
MODEL
4 3 2 1 0 4 8 FT
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
SAN FRANCISCO BAY
N
SOLID BREAKWATER
SOLID BREAKWATER
SEGMENTED BREAKWATER (28-FT STRUCTURES, 6-FT OPENINGS)
PLAN 64
PLAN 65
PLAN 66
PIER 45
FISH ALLEY
HYDE STREET PIER
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0
1A
2A
3A
4A
5A
6A
7A
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

PLATE 26



ELEMENTS OF PLANS 67-69
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
N
SAN FRANCISCO BAY
PLAN 67
PLAN 68
PLAN 69
SOLID BREAKWATER
SEGMENTED BREAKWATER (28-FT STRUCTURES, 6-FT OPENINGS)
PIER 45
FISH ALLEY
HYDE STREET PIER
SEAWALL
AQUATIC PARK
MUNICIPAL PIER
-40
-30
-20
-10
0
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 27

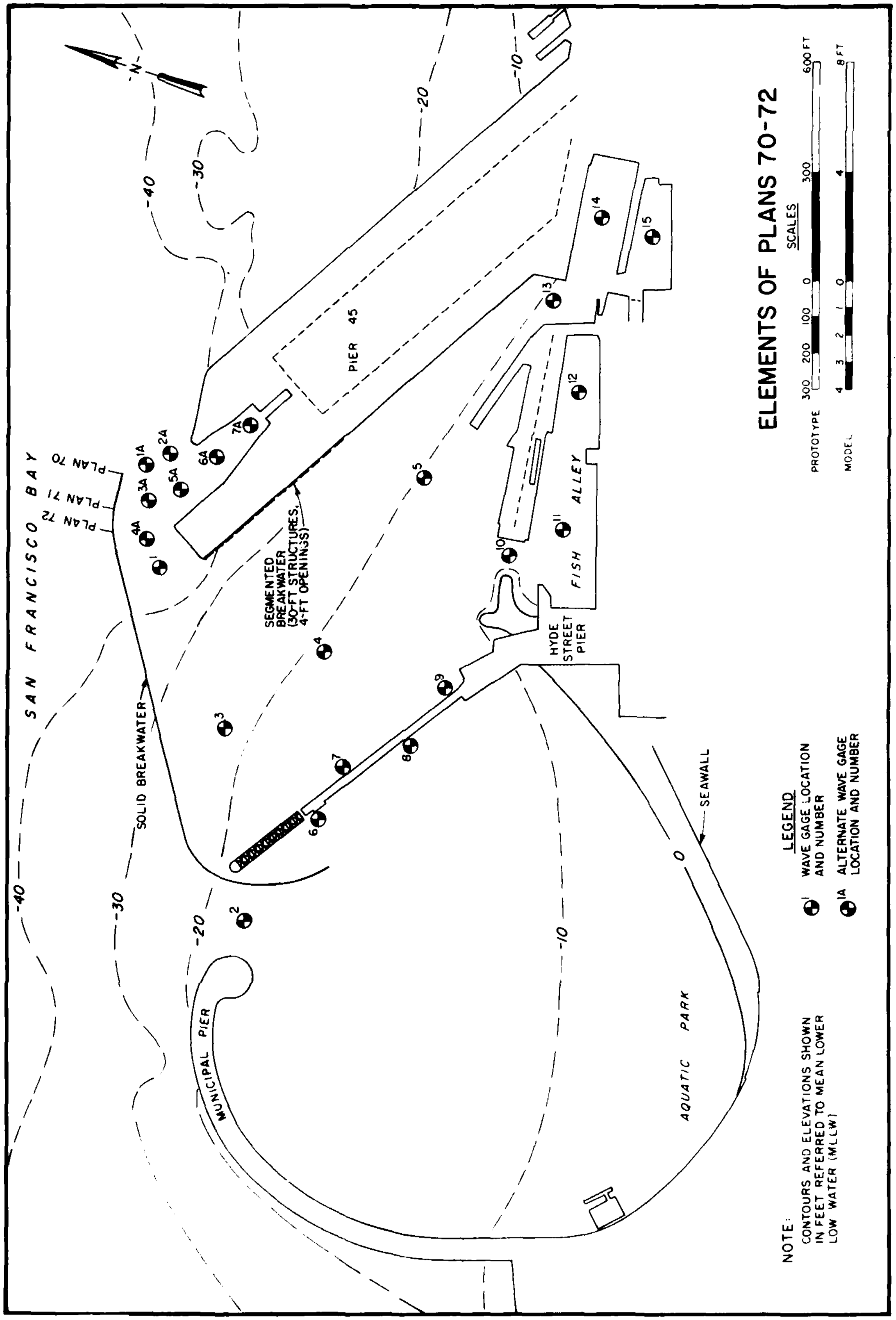
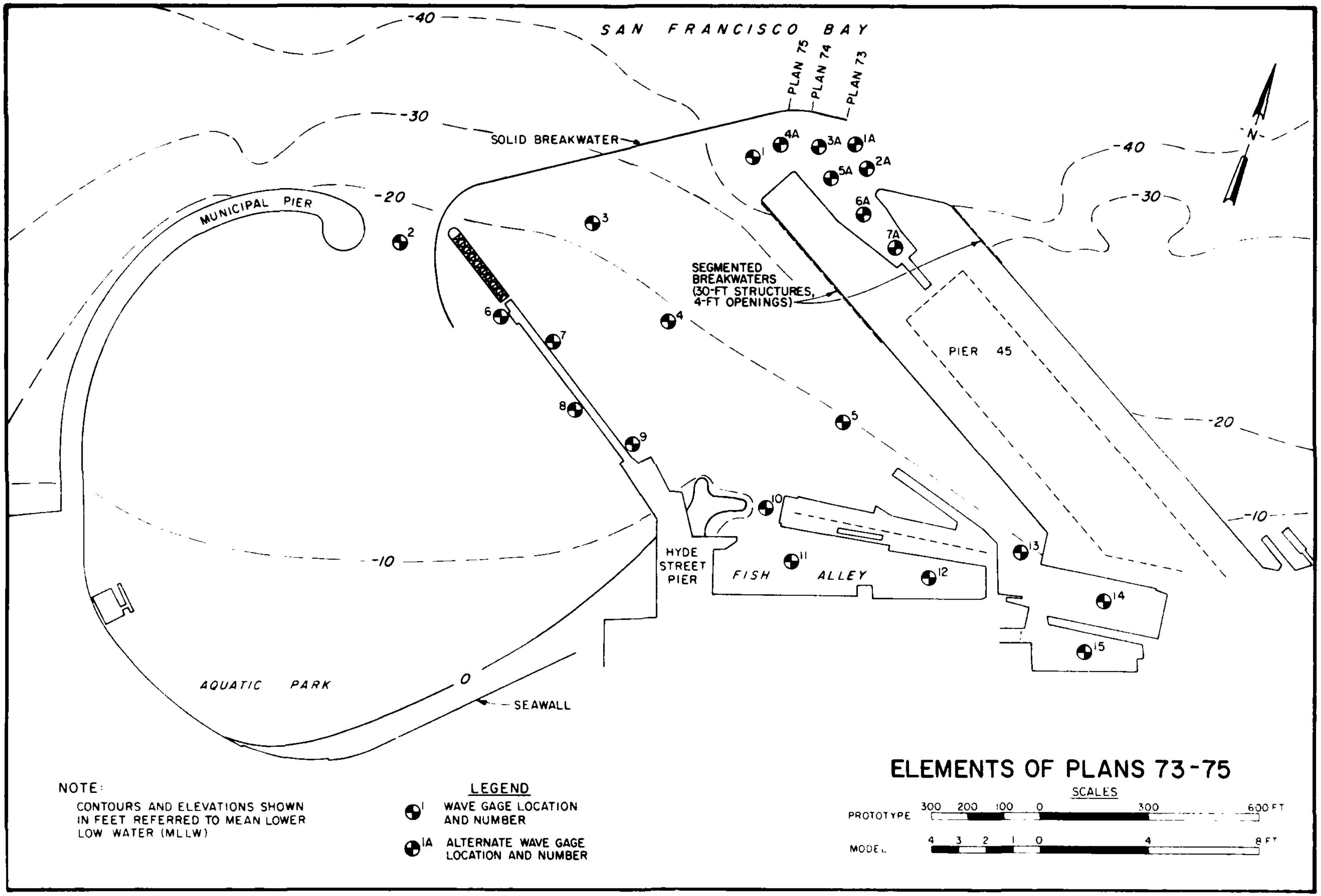
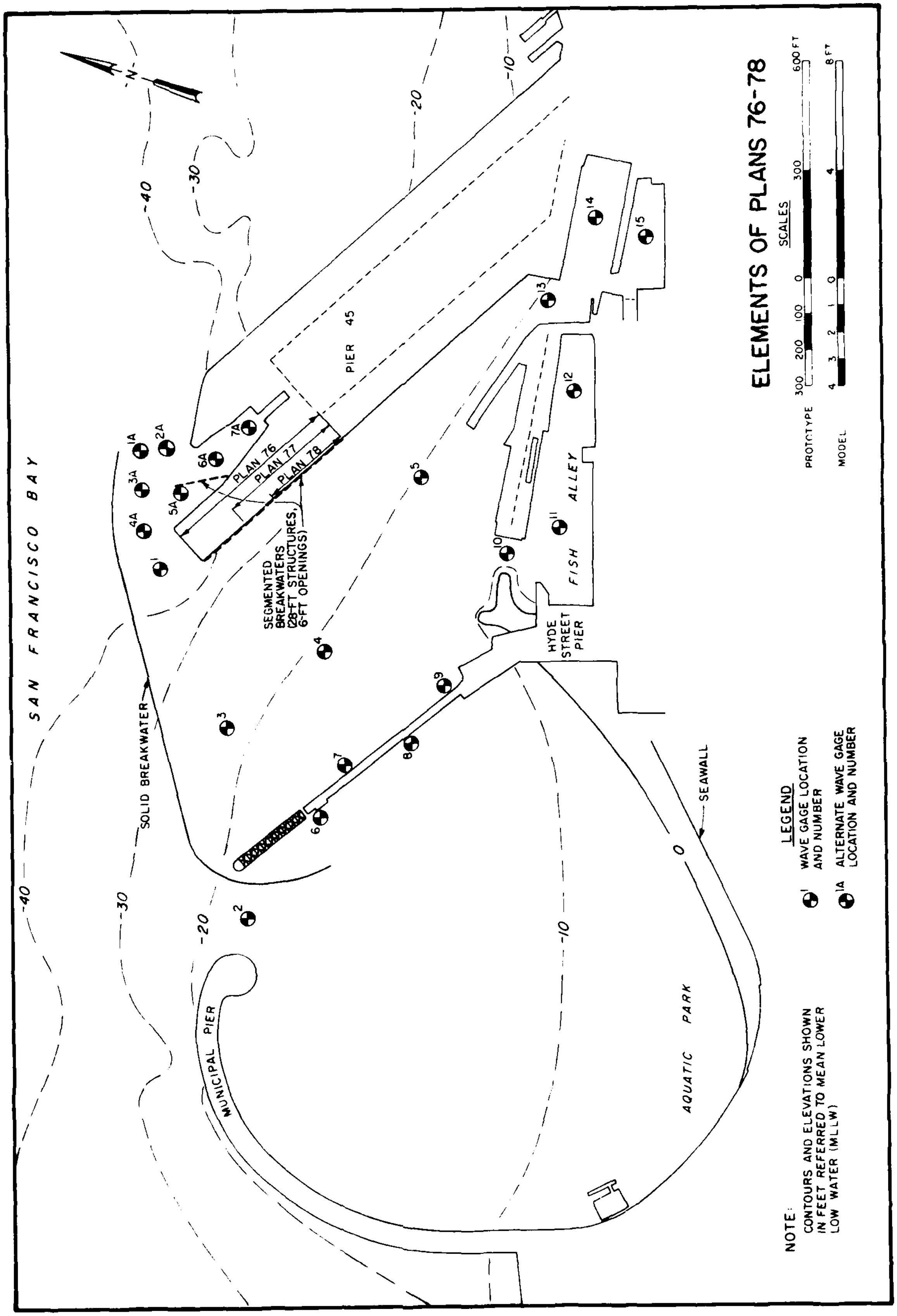

ELEMENTS OF PLANS 70-72
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
N
SAN FRANCISCO BAY
PLAN 70
PLAN 71
PLAN 72
SOLID BREAKWATER
SEGMENTED BREAKWATER (30-FT STRUCTURES, 4-FT OPENINGS)
PIER 45
HYDE STREET PIER
FISH ALLEY
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1A
2A
3A
4A
5A
6A
7A

PLATE 28

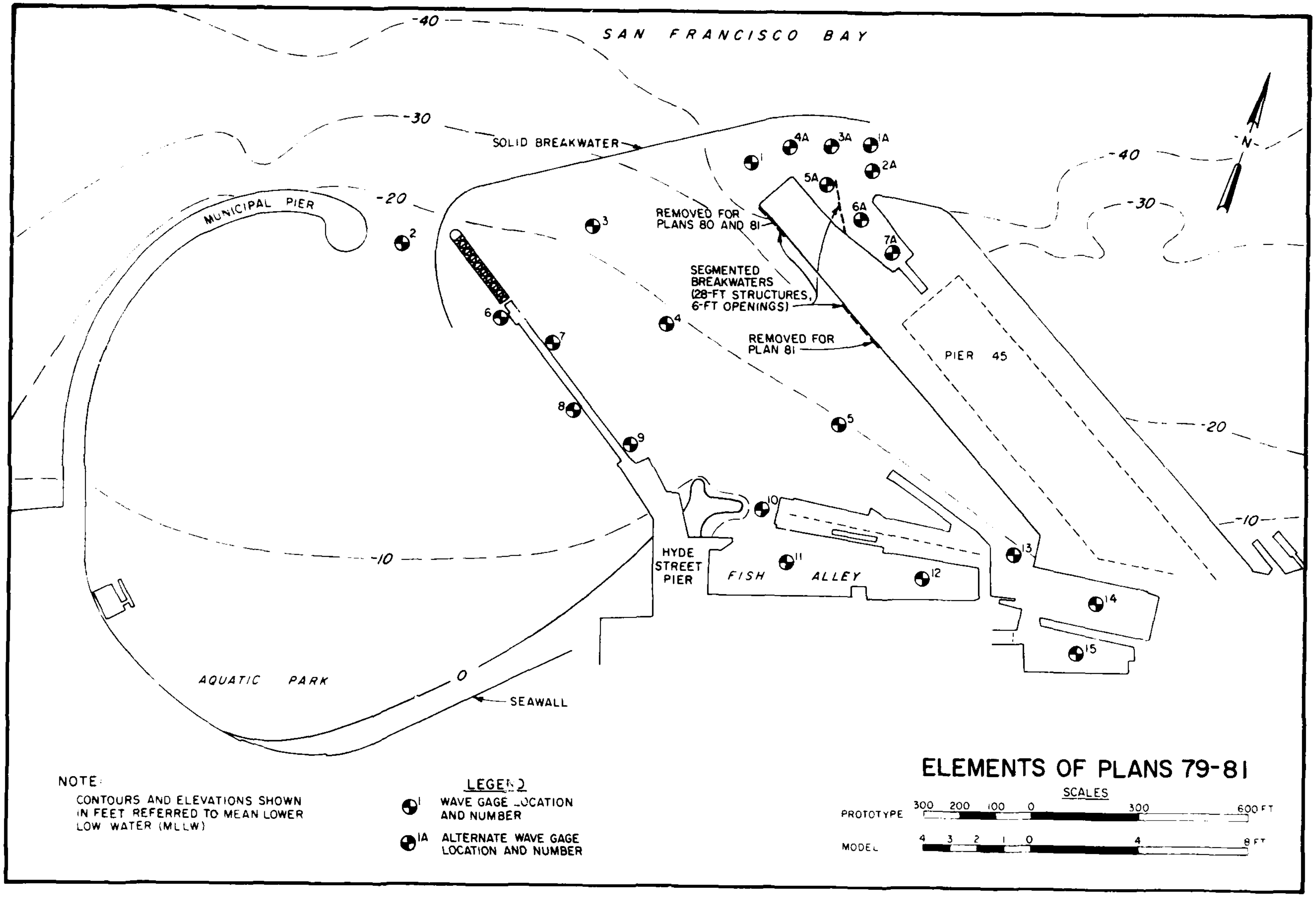


ELEMENTS OF PLANS 73-75



ELEMENTS OF PLANS 76-78
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
N
SAN FRANCISCO BAY
SOLID BREAKWATER
SEGMENTED BREAKWATERS (28-FT STRUCTURES, 6-FT OPENINGS)
PLAN 76
PLAN 77
PLAN 78
PIER 45
FISH ALLEY
HYDE STREET PIER
MUNICIPAL PIER
AQUATIC PARK
SEAWALL
-40
-30
-20
-10
0
1A
2A
3A
4A
5A
6A
7A
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 30



ELEMENTS OF PLANS 79-81

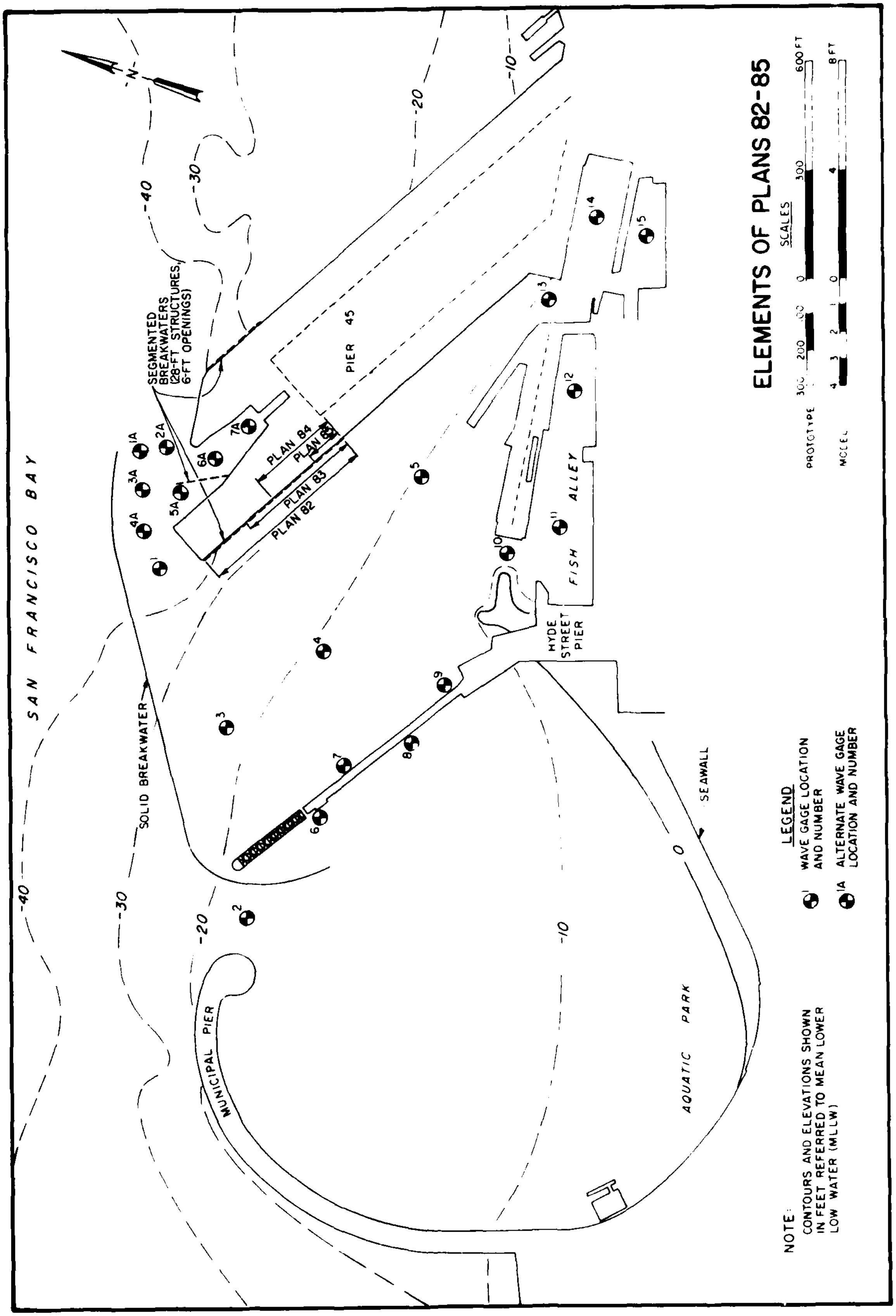
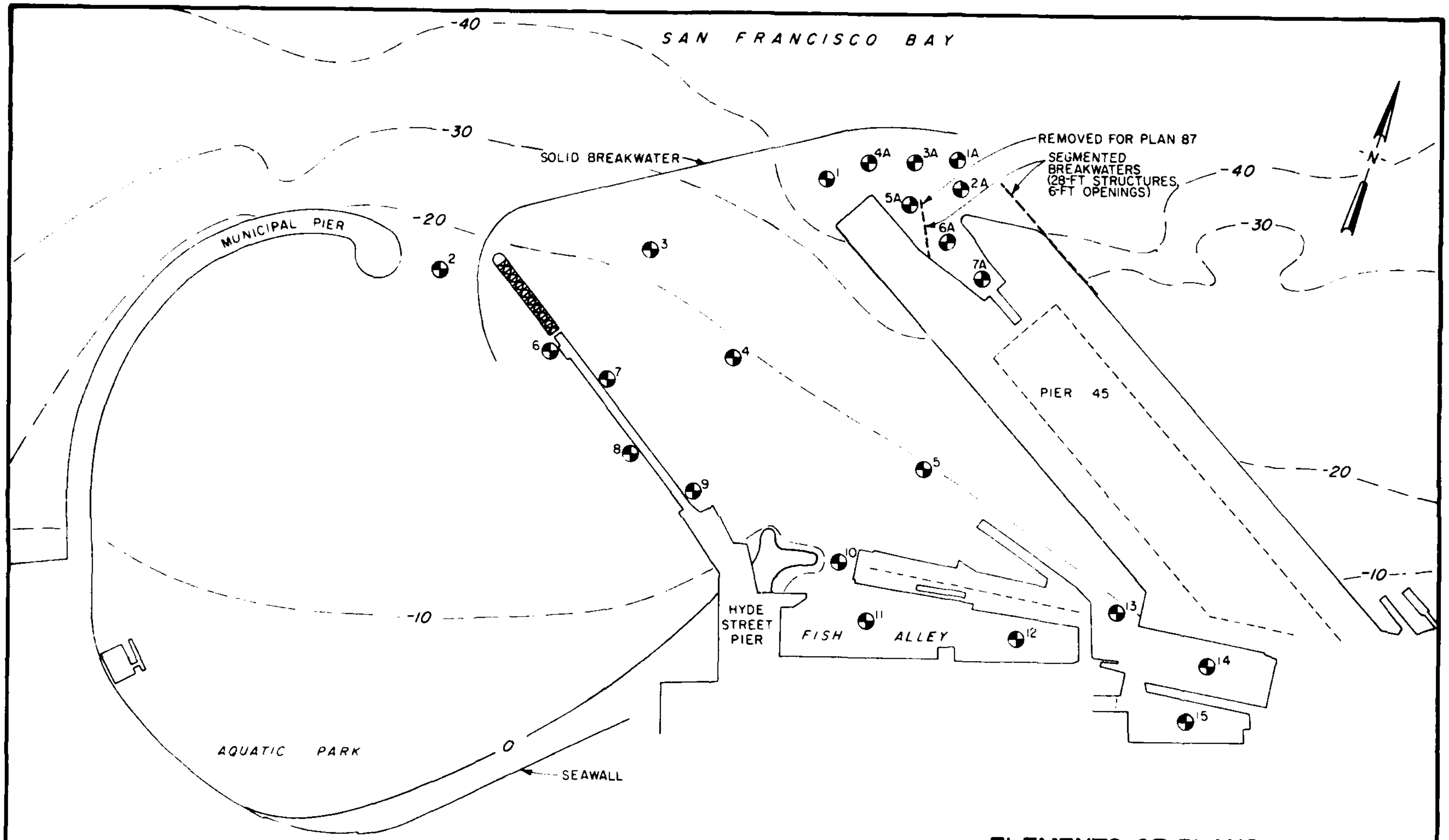

ELEMENTS OF PLANS 82-85
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)
N
SAN FRANCISCO BAY
SOLID BREAKWATER
SEGMENTED BREAKWATERS (28-FT STRUCTURES, 6-FT OPENINGS)
PIER 45
PLAN 82
PLAN 83
PLAN 84
PLAN 85
HYDE STREET PIER
FISH ALLEY
SEAWALL
AQUATIC PARK
MUNICIPAL PIER
-40
-30
-20
-10
0

PLATE 32



ELEMENTS OF PLANS 86 AND 87

SCALES

PROTOTYPE 300 200 100 0 300 600 FT

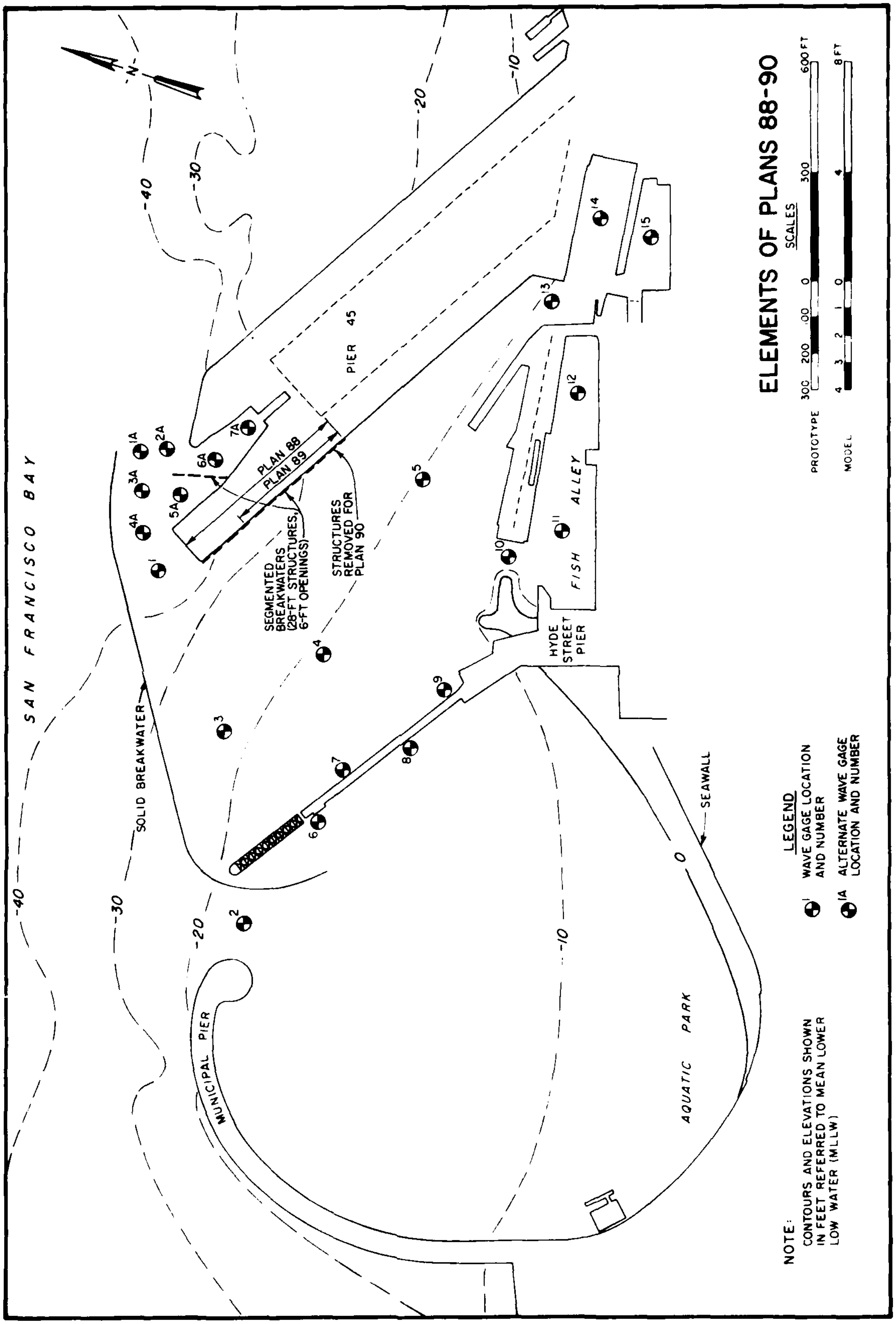
MODEL 4 3 2 1 0 4 8 FT

NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

LEGEND

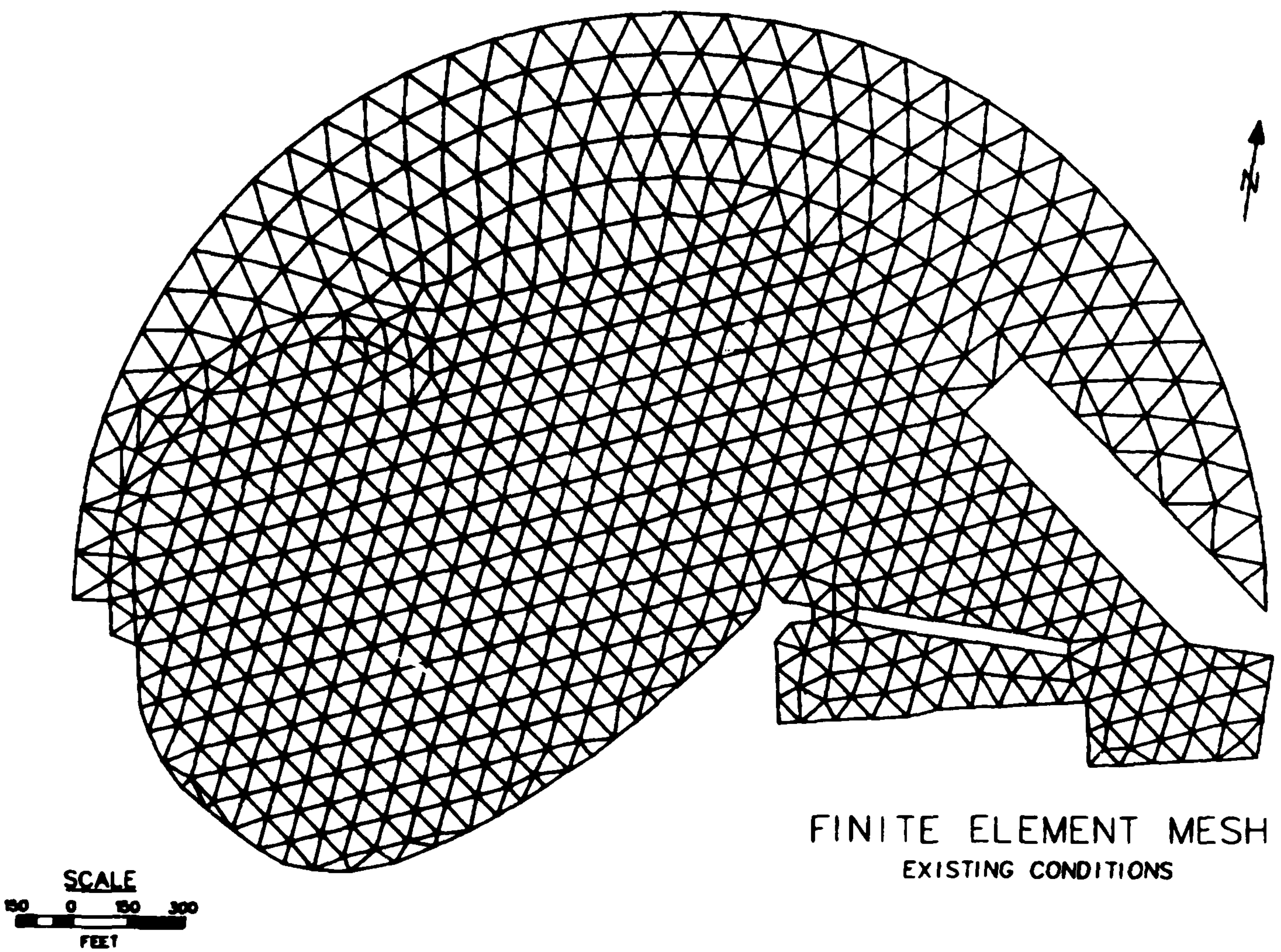
1 WAVE GAGE LOCATION AND NUMBER

1A ALTERNATE WAVE GAGE LOCATION AND NUMBER

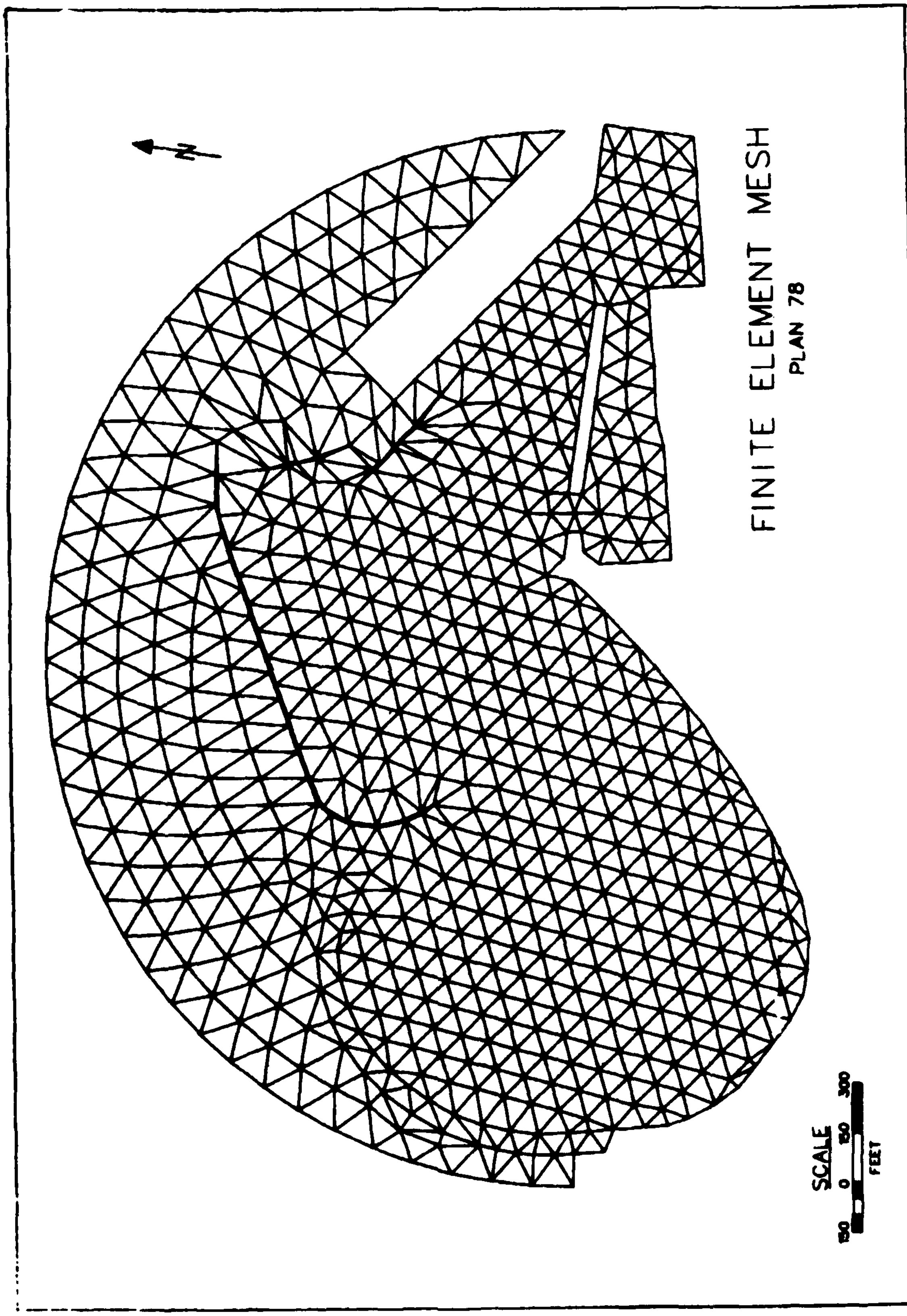


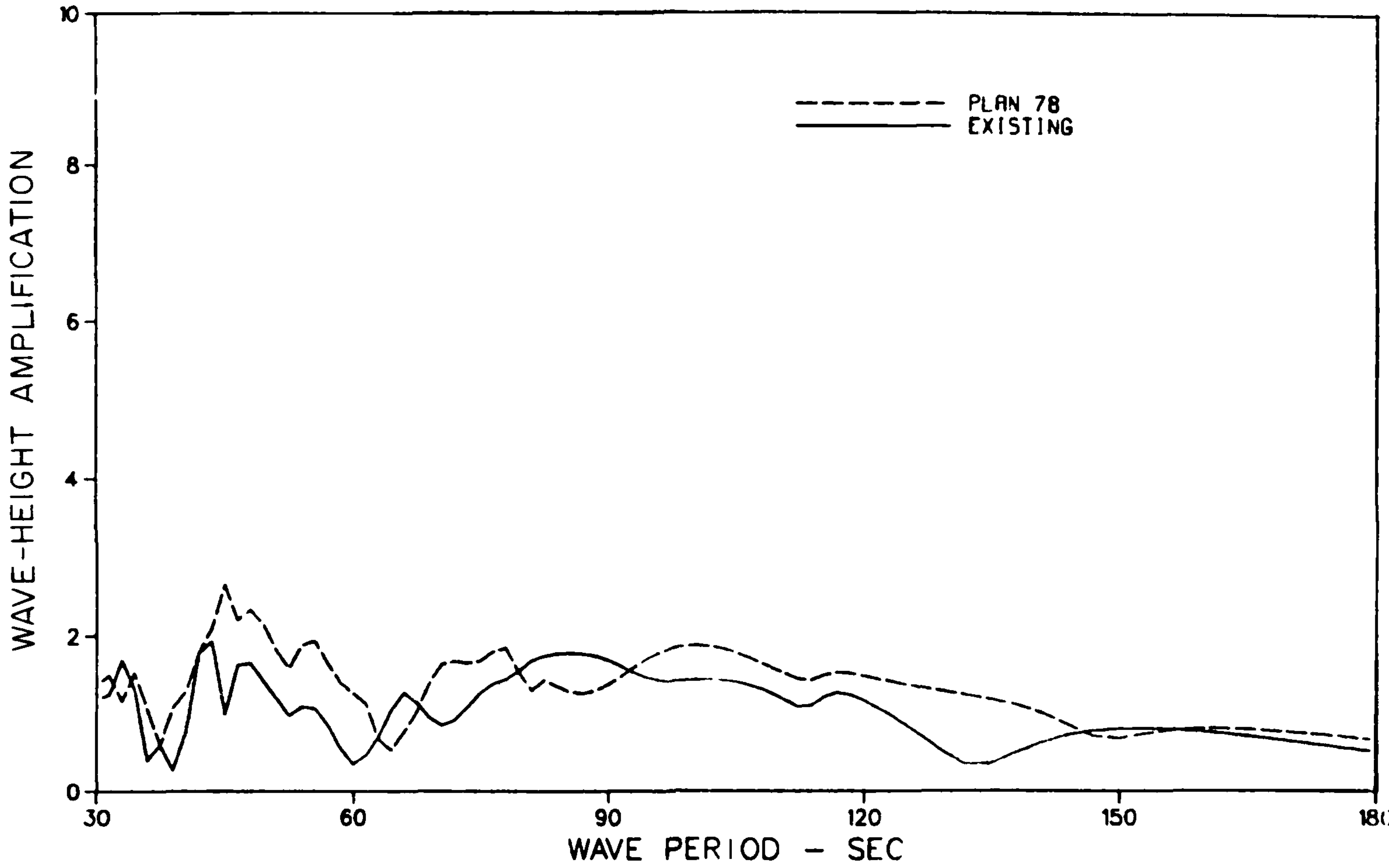
ELEMENTS OF PLANS 88-90
SCALES
PROTOTYPE 300 200 100 0 300 600 FT
MODEL 4 3 2 1 0 4 8 FT
SAN FRANCISCO BAY
N
-40
-30
-20
-10
0
PIER 45
PLAN 88
PLAN 89
SEGMENTED BREAKWATERS (28-FT STRUCTURES, 6-FT OPENINGS)
STRUCTURES REMOVED FOR PLAN 90
SOLID BREAKWATER
FISH ALLEY
HYDE STREET PIER
SEAWALL
MUNICIPAL PIER
AQUATIC PARK
1A
2A
3A
4A
5A
6A
7A
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
LEGEND
WAVE GAGE LOCATION AND NUMBER
ALTERNATE WAVE GAGE LOCATION AND NUMBER
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOWER LOW WATER (MLLW)

PLATE 34

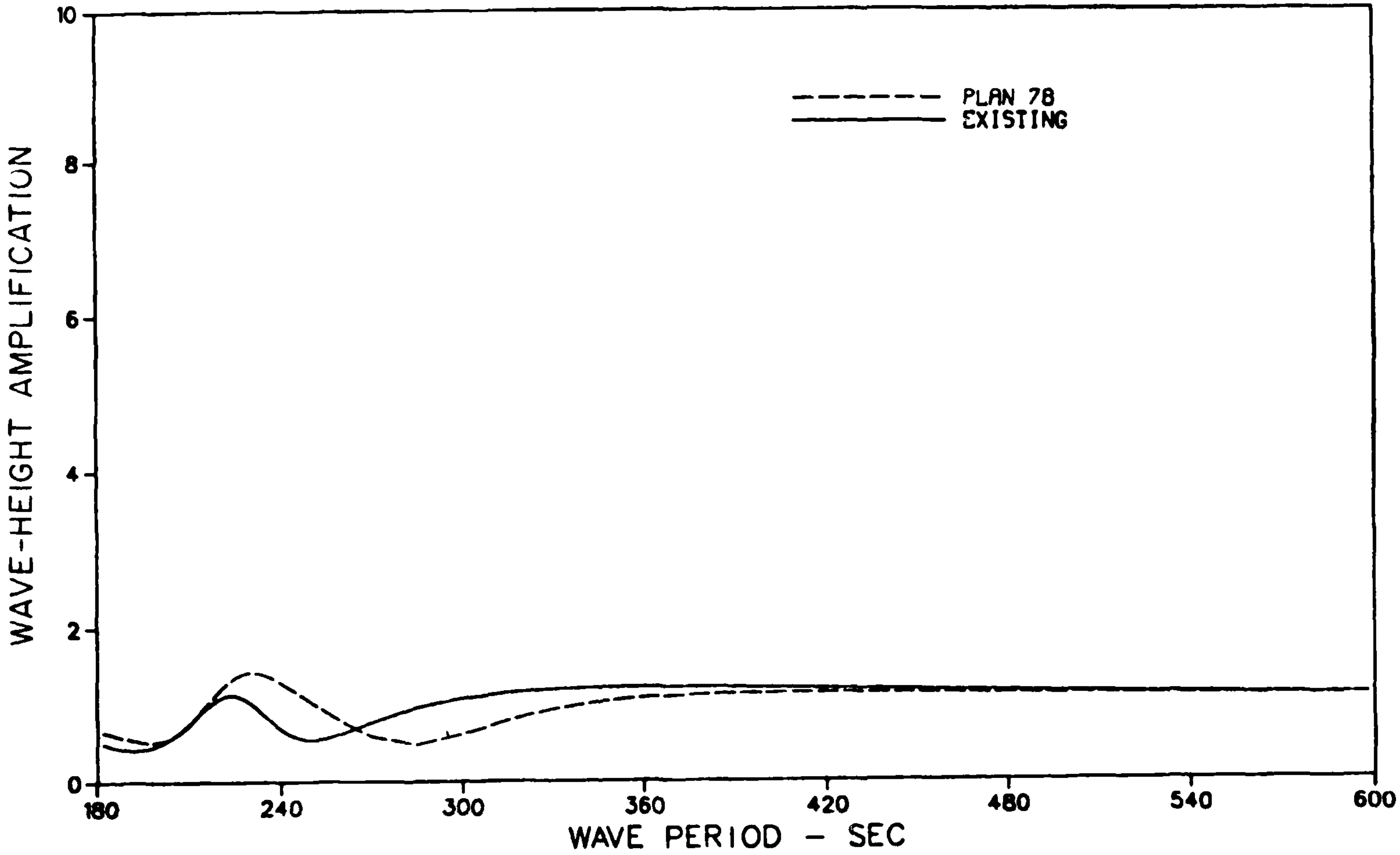


FINITE ELEMENT MESH
EXISTING CONDITIONS

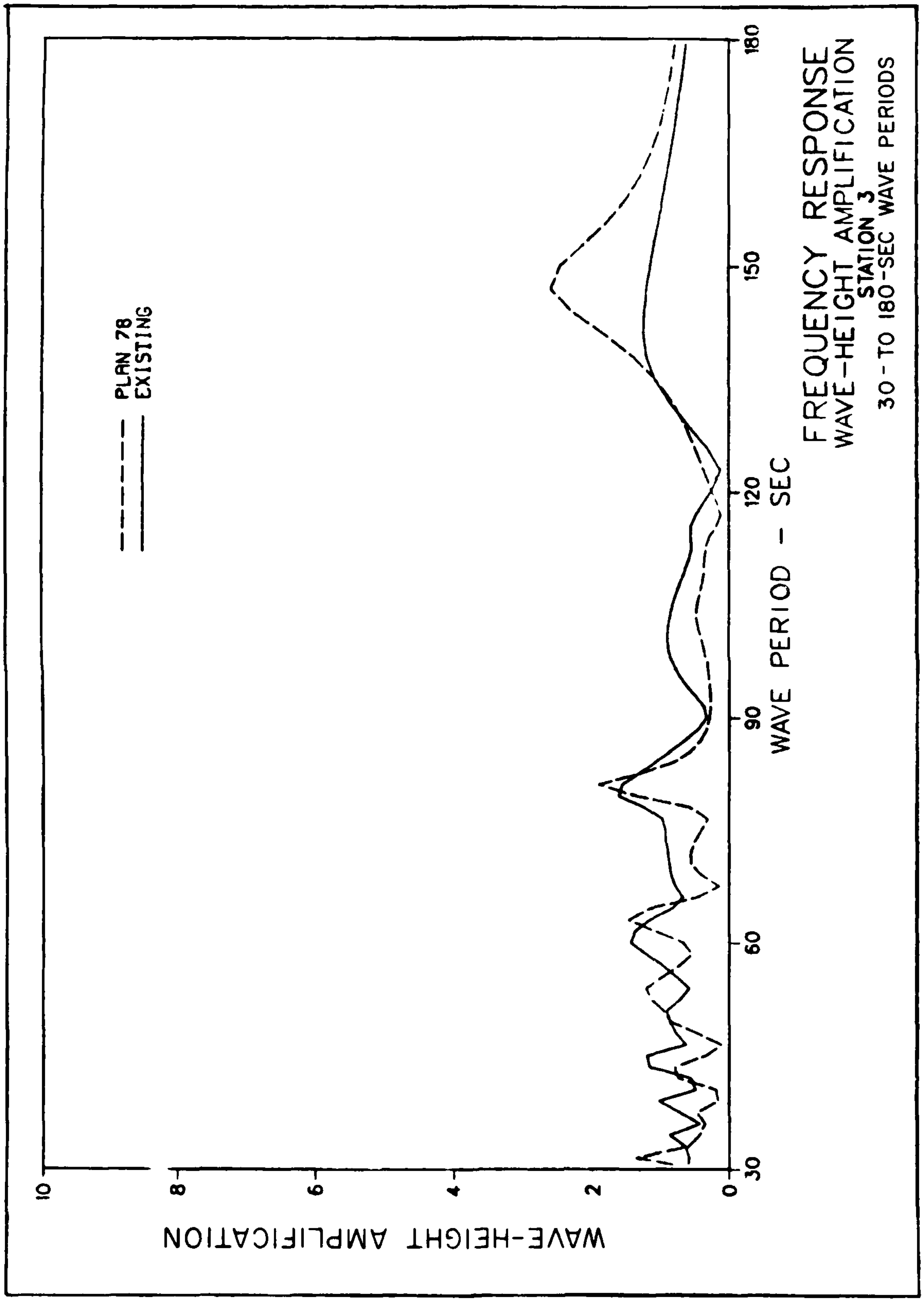

FINITE ELEMENT MESH
PLAN 7B
N
SCALE
150 0 150 300
FEET



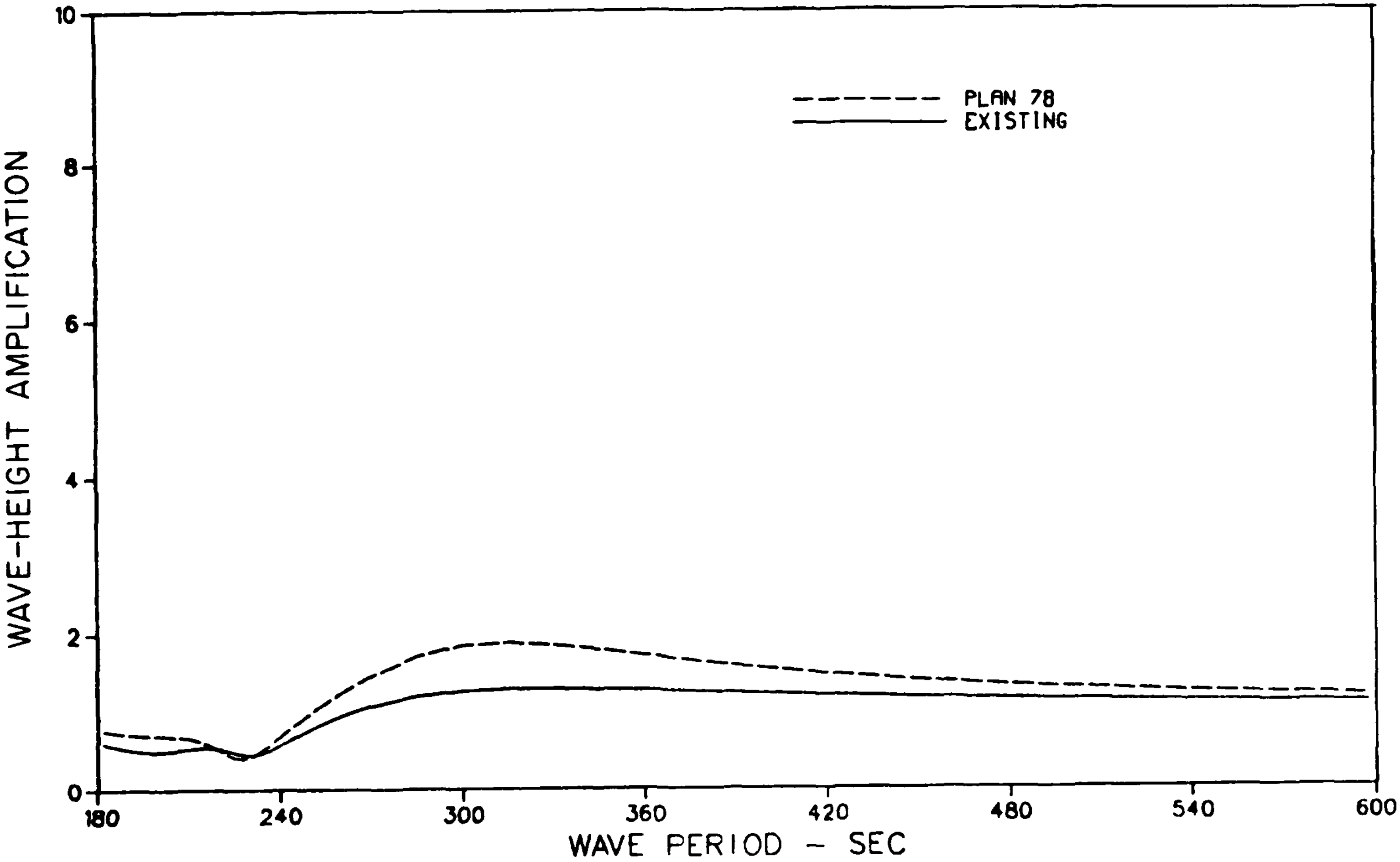
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 2
30- TO 180-SEC WAVE PERIODS



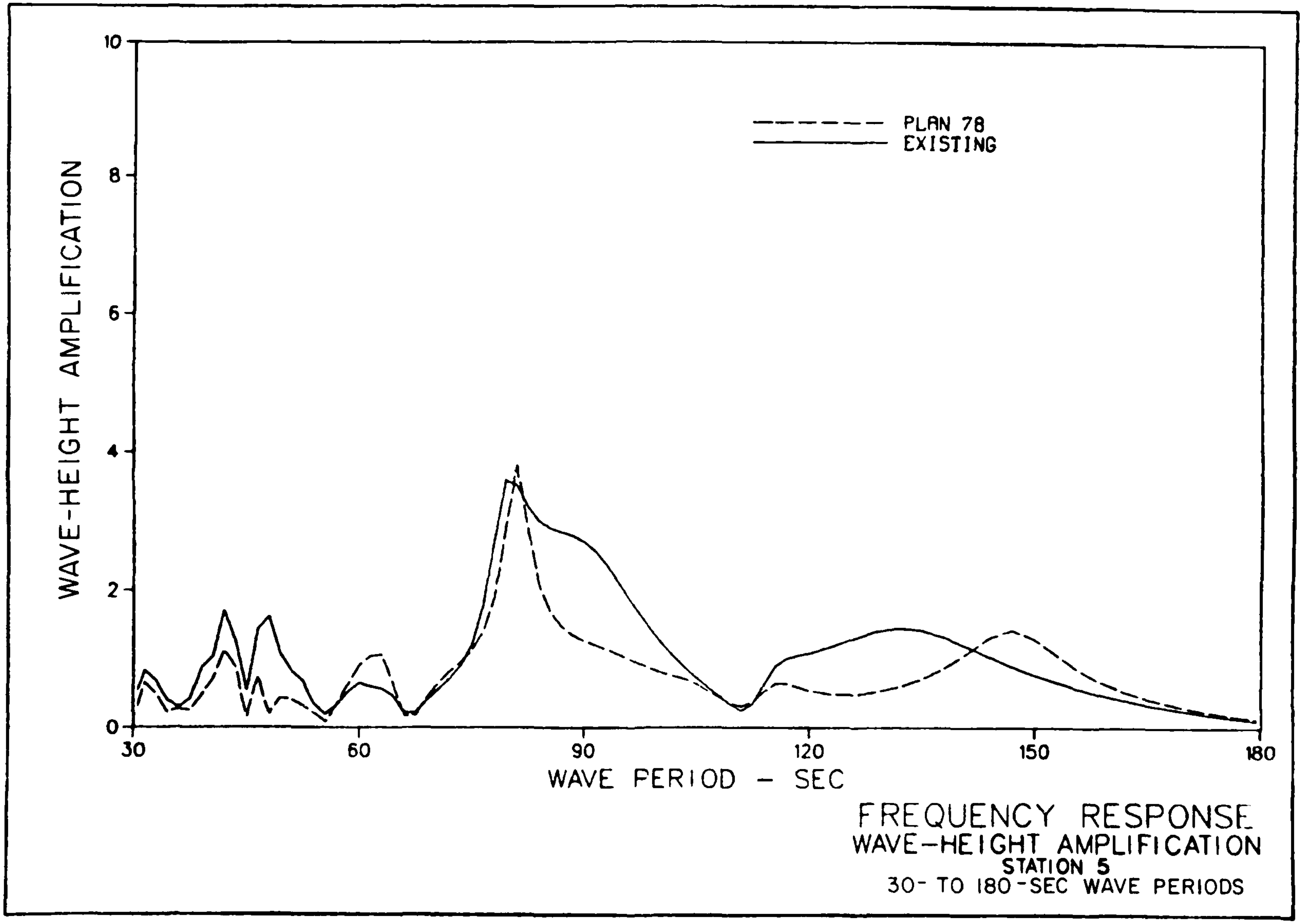
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 2
180-TO 600-SEC WAVE PERIODS

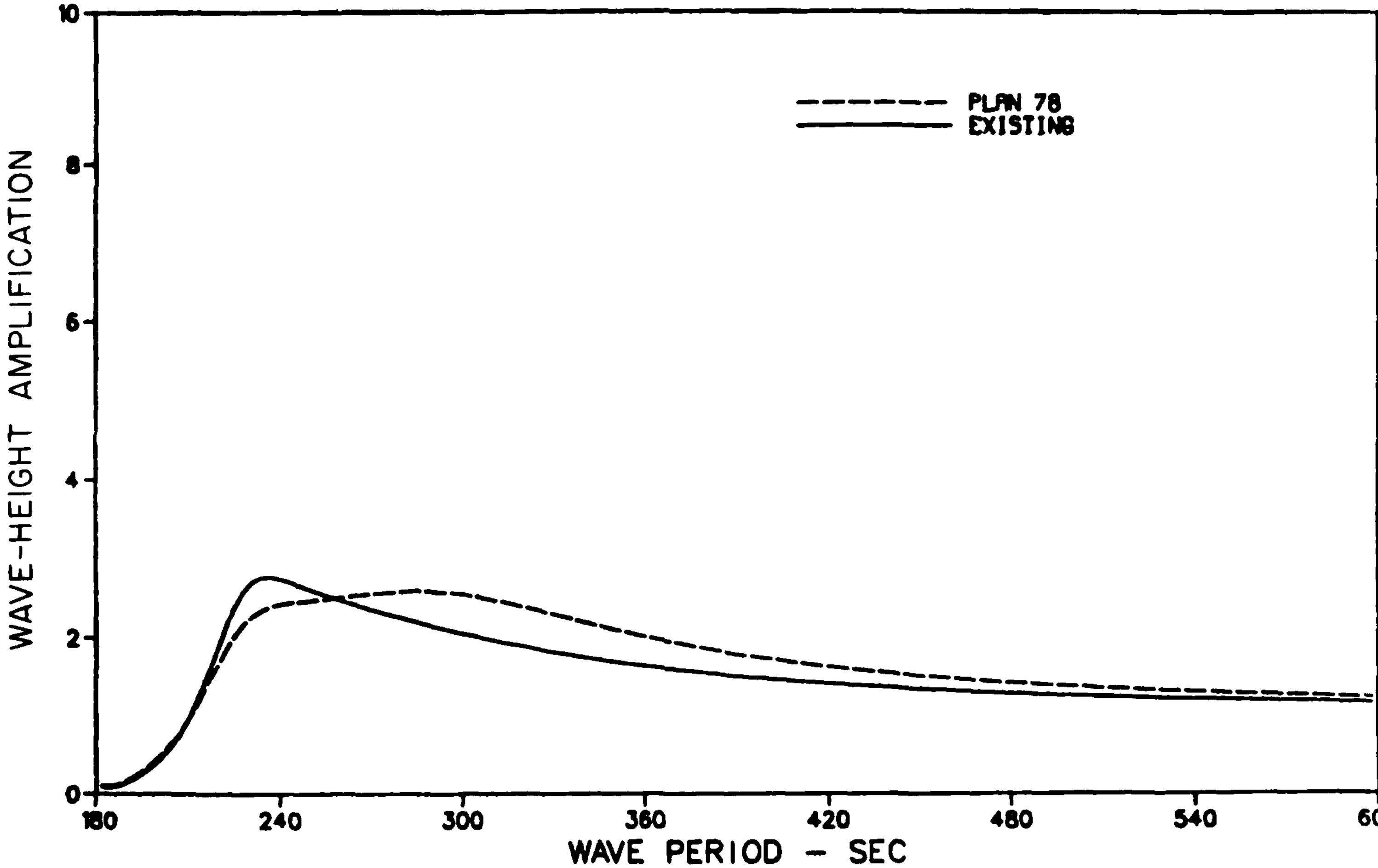


FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 3
30- TO 180-SEC WAVE PERIODS
PLAN 7B
EXISTING
WAVE-HEIGHT AMPLIFICATION
WAVE PERIOD - SEC
0
2
4
6
8
10
30
60
90
120
150
180

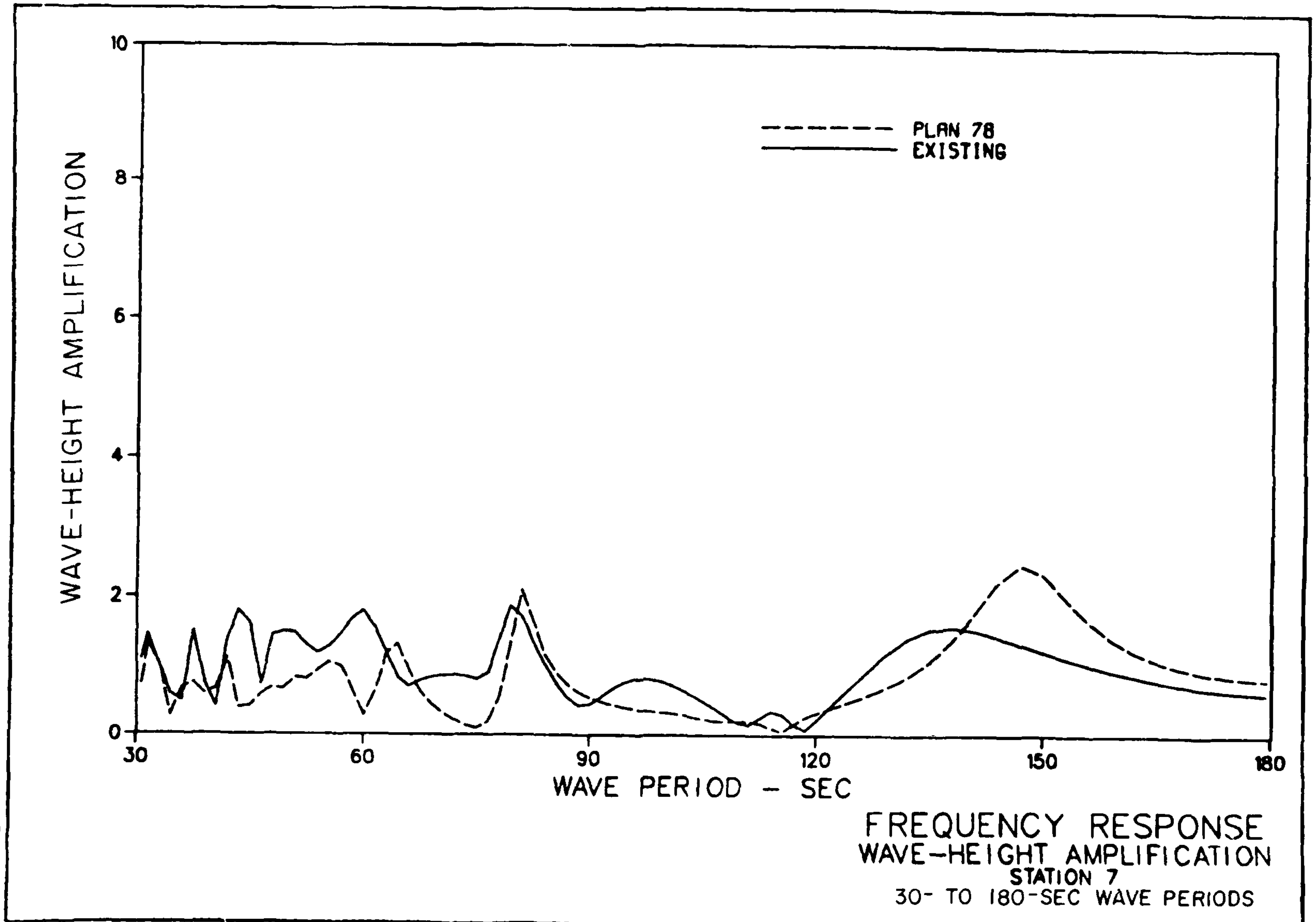


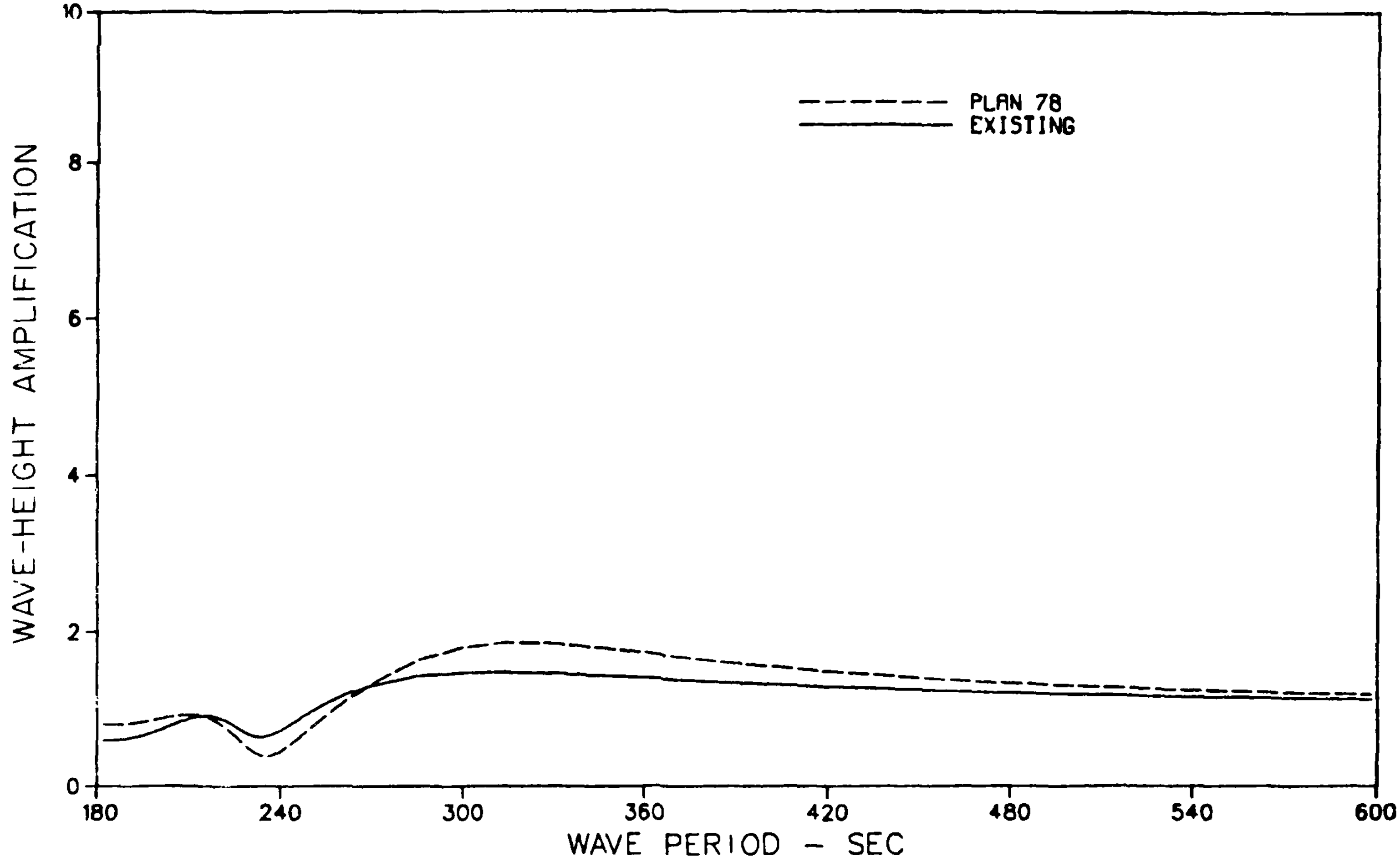
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 3
180- TO 600-SEC WAVE PERIODS


PLAN 78
EXISTING
WAVE-HEIGHT AMPLIFICATION
10
8
6
4
2
0
30
60
90
120
150
180
WAVE PERIOD - SEC
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 5
30- TO 180-SEC WAVE PERIODS



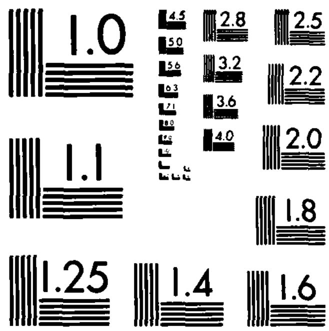
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 5
180- TO 600-SEC WAVE PERIODS


WAVE-HEIGHT AMPLIFICATION
0
2
4
6
8
10
30
60
90
120
150
180
WAVE PERIOD - SEC
PLAN 78
EXISTING
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 7
30- TO 180-SEC WAVE PERIODS

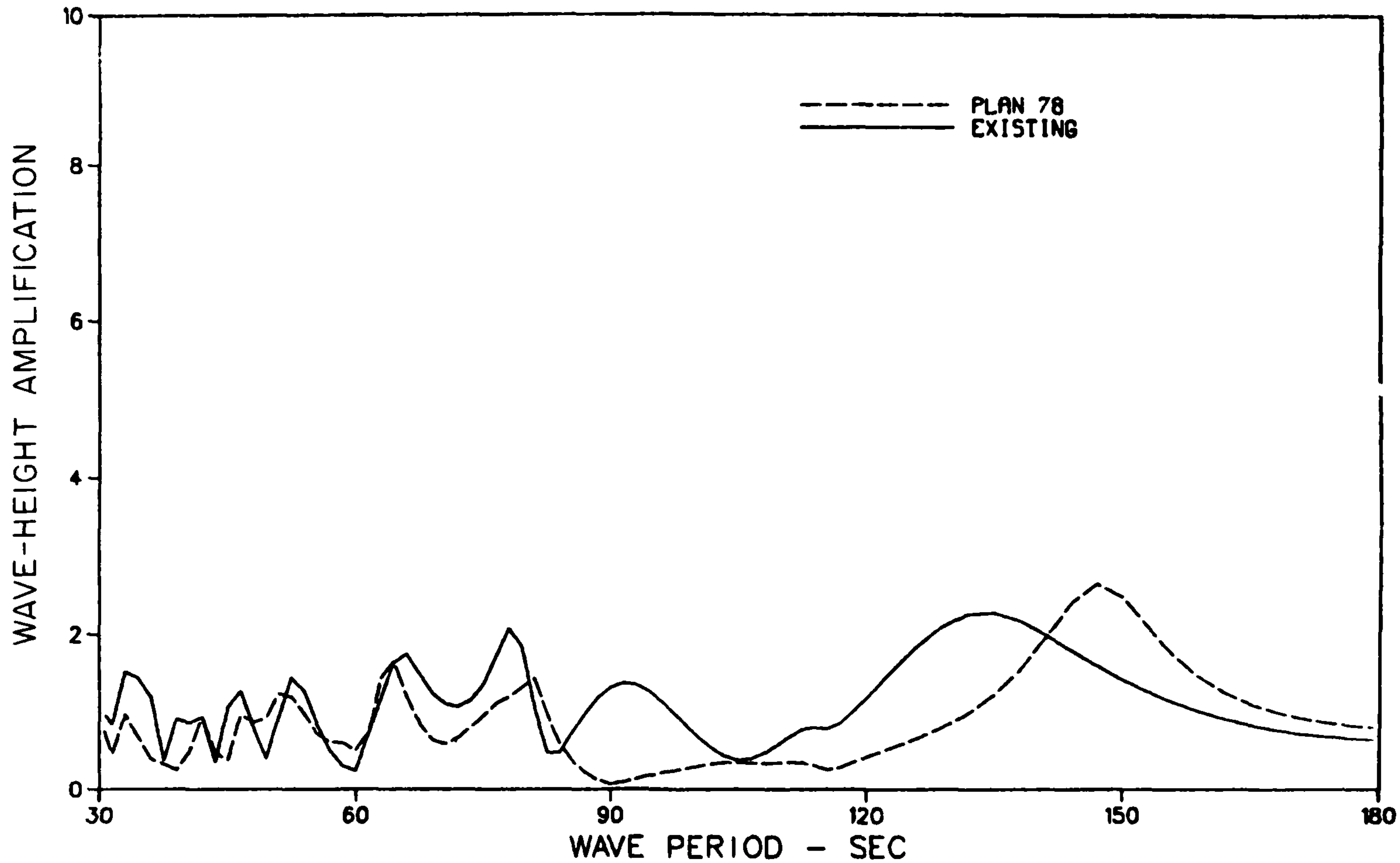


FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 7
180- TO 600-SEC WAVE PERIODS

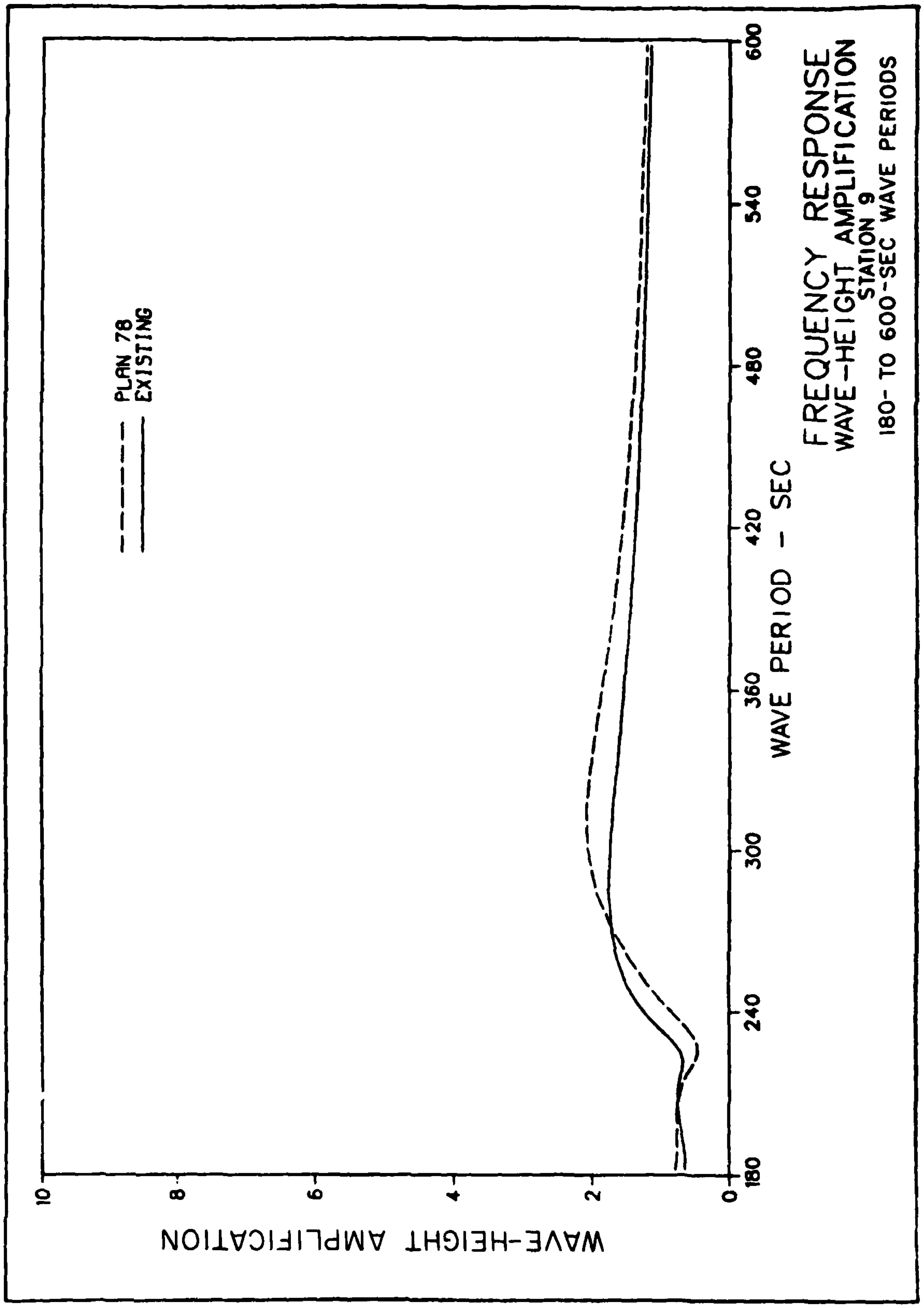
AD-A165 133   FISHERMAN'S WHARF AREA SAN FRANCISCO BAY CALIFORNIA   4/4
DESIGN FOR WAVE PROTECTION(U) COASTAL ENGINEERING
RESEARCH CENTER VICKSBURG MS R R BOTTIN ET AL. OCT 85
UNCLASSIFIED   CECC-85-7   F/G 13/2   NL



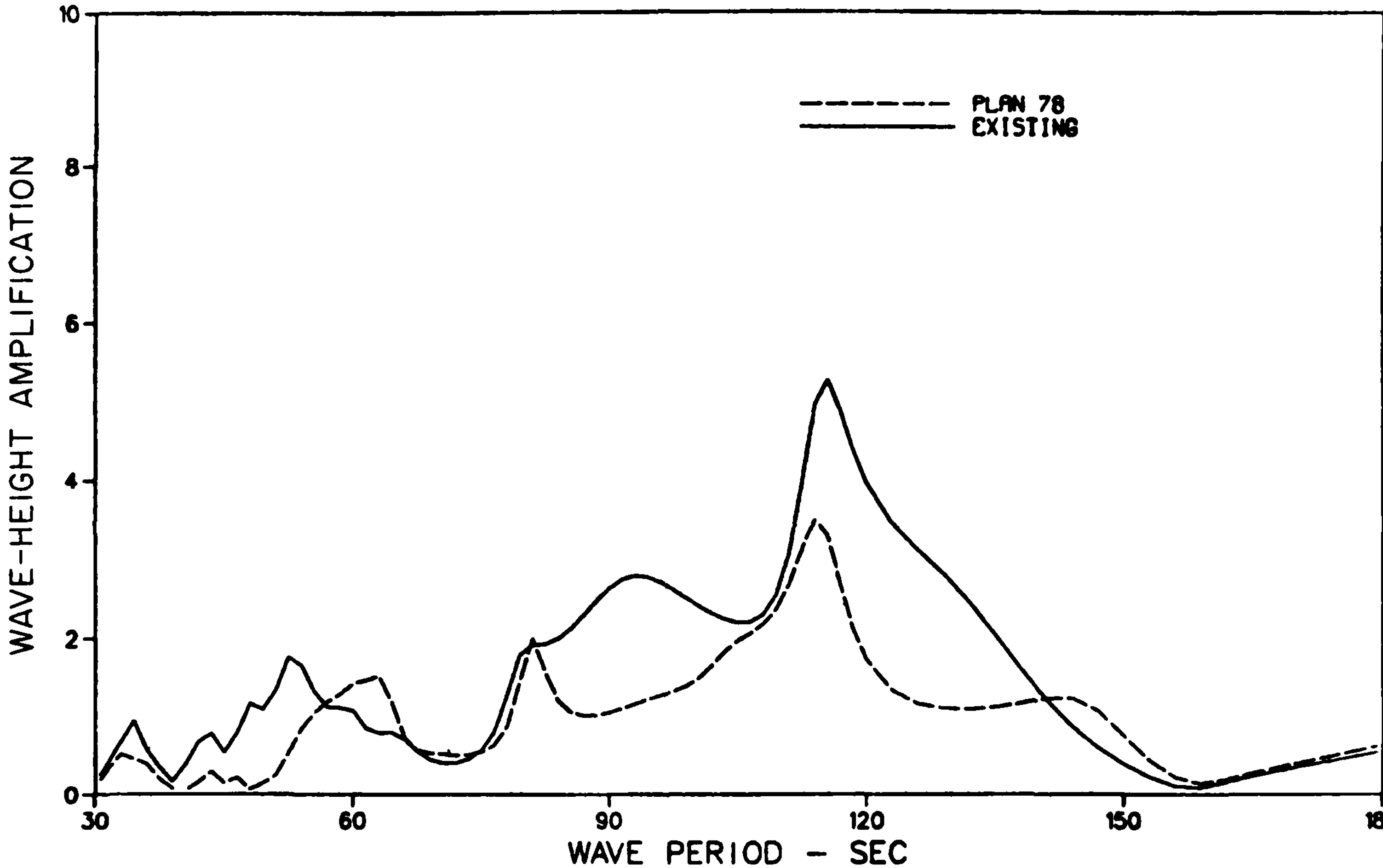
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



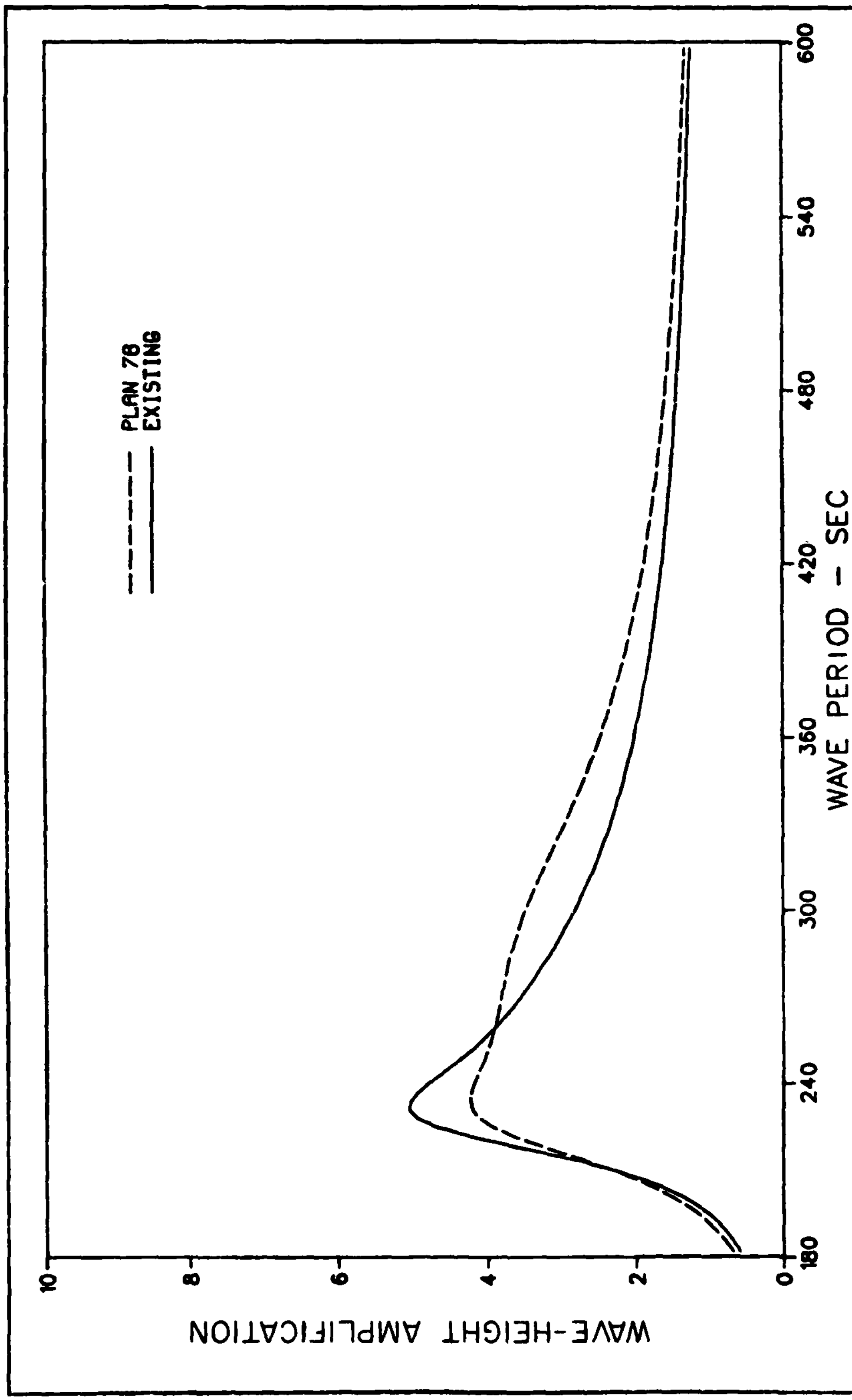
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 9
30- TO 180-SEC WAVE PERIODS



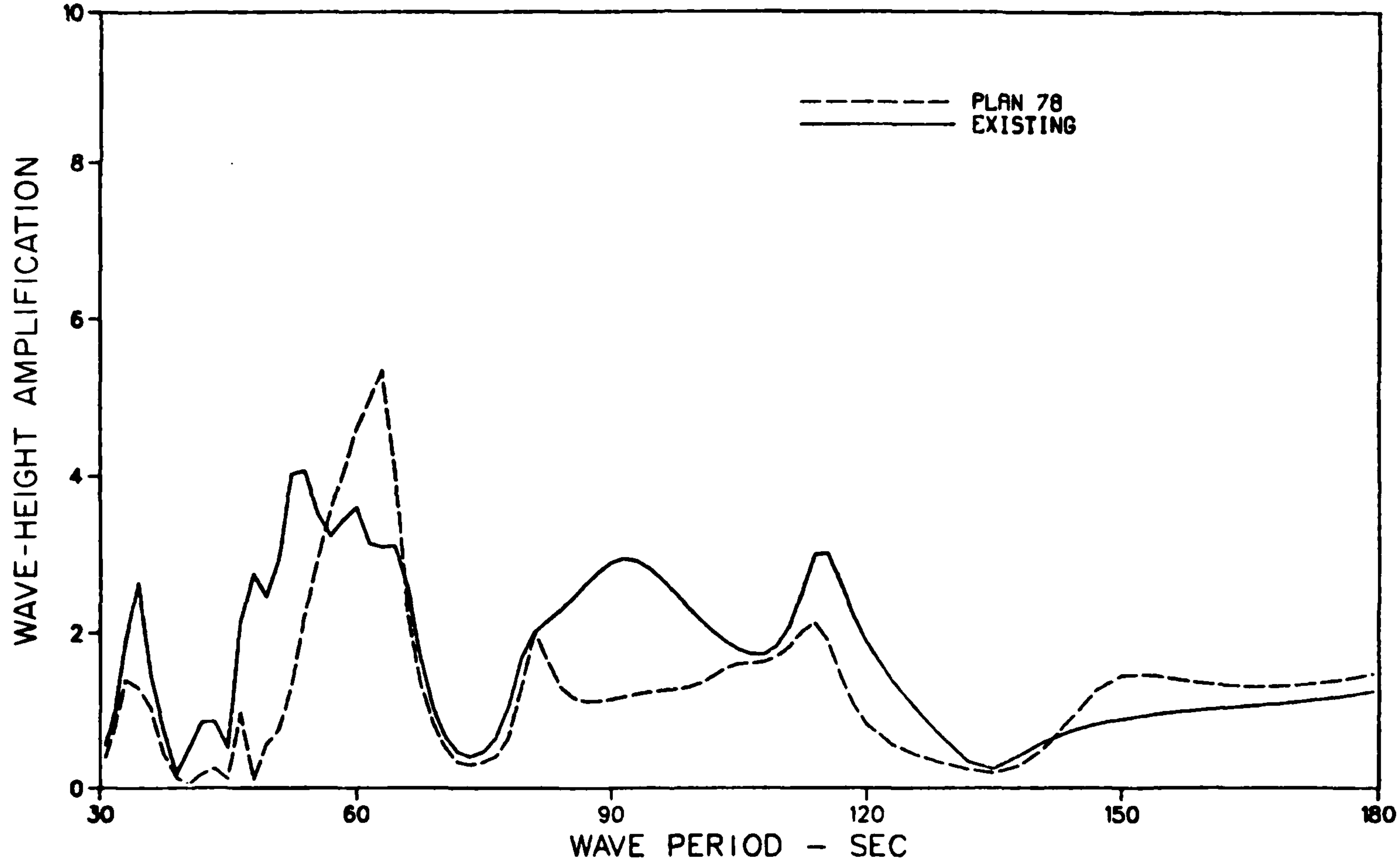
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 9
180- TO 600-SEC WAVE PERIODS
PLAN 78
EXISTING
WAVE-HEIGHT AMPLIFICATION
WAVE PERIOD - SEC
0
2
4
6
8
10
180
240
300
360
420
480
540
600



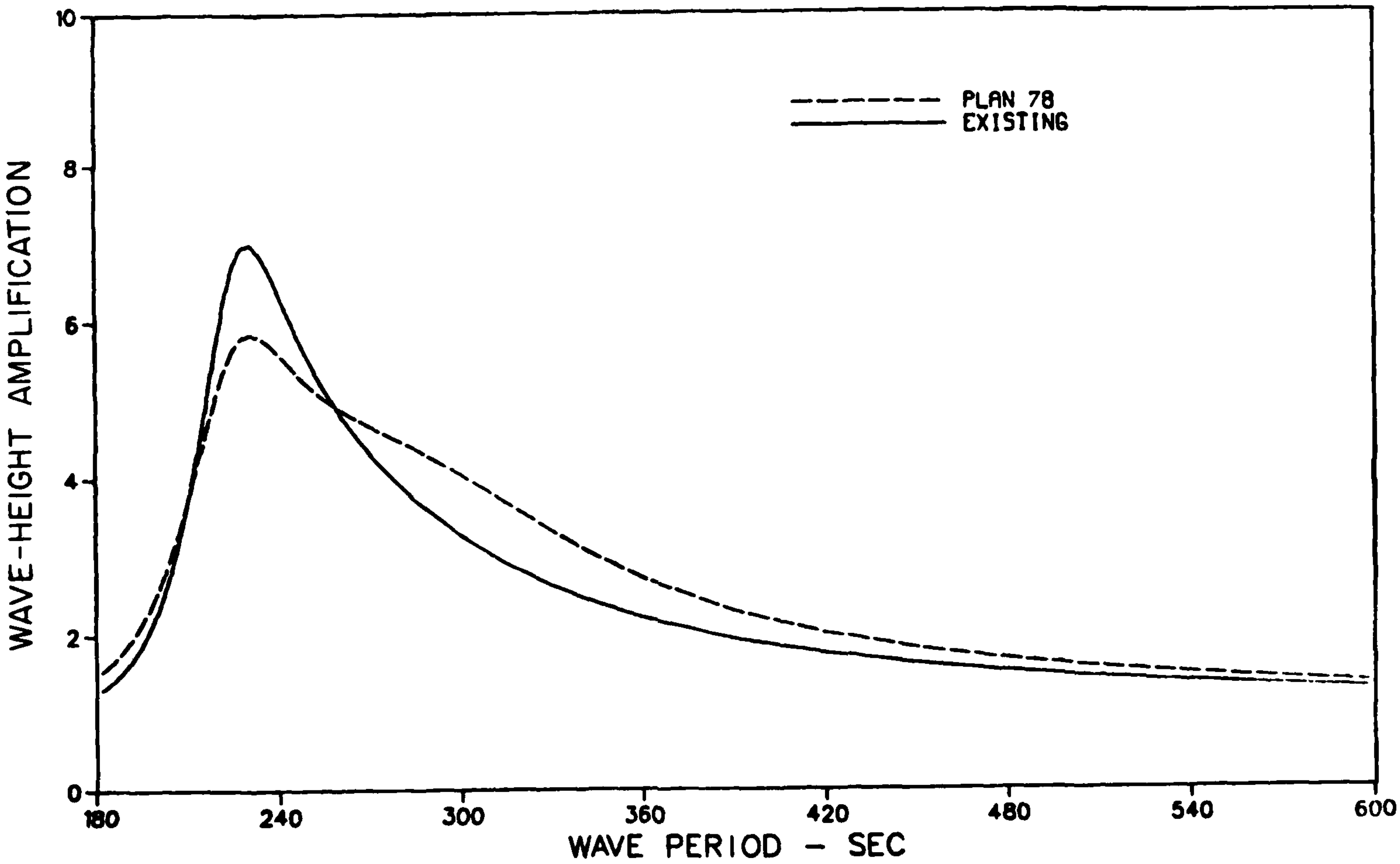
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 11
30- TO 180-SEC WAVE PERIODS



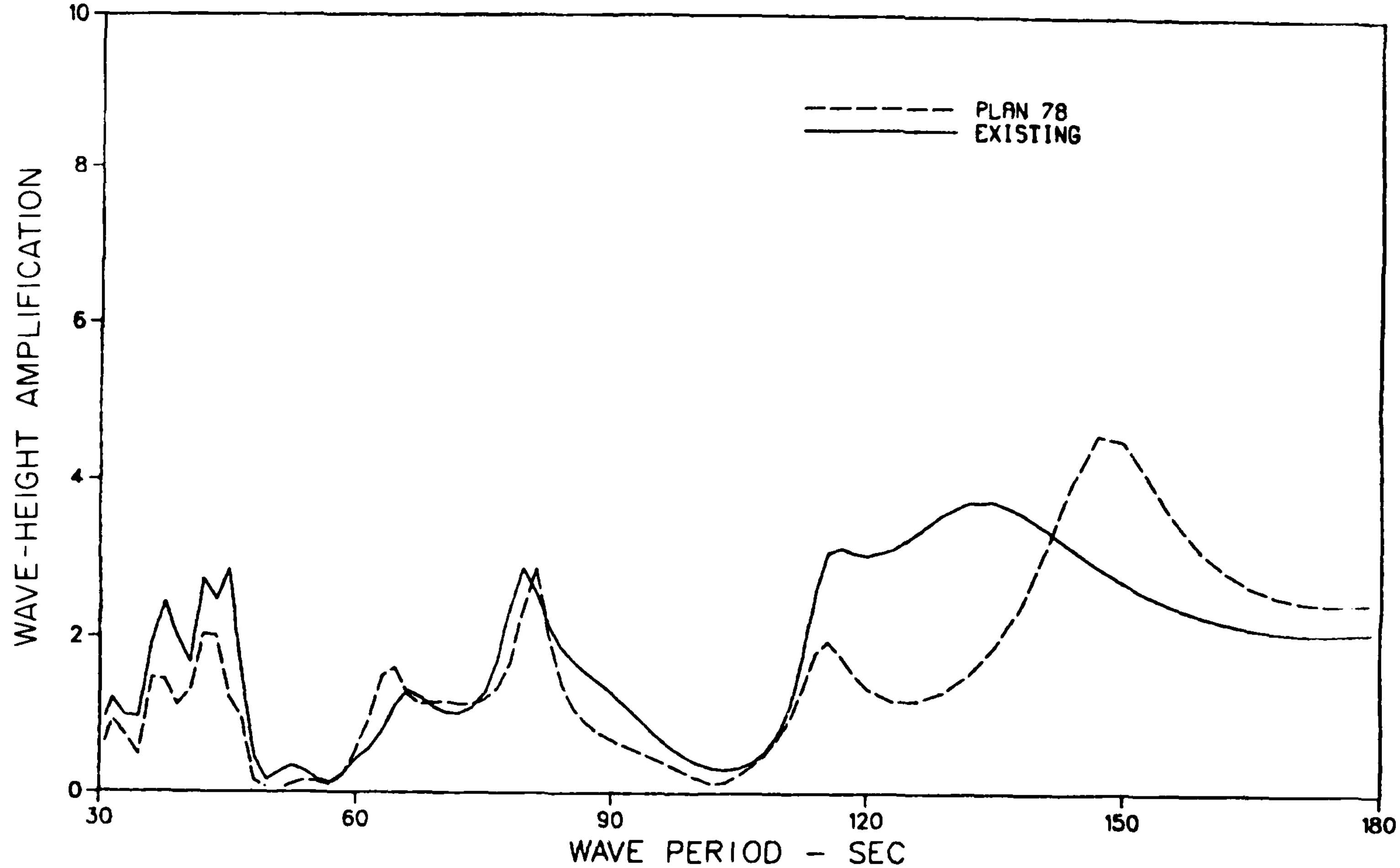
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 11
180- TO 600-SEC WAVE PERIODS



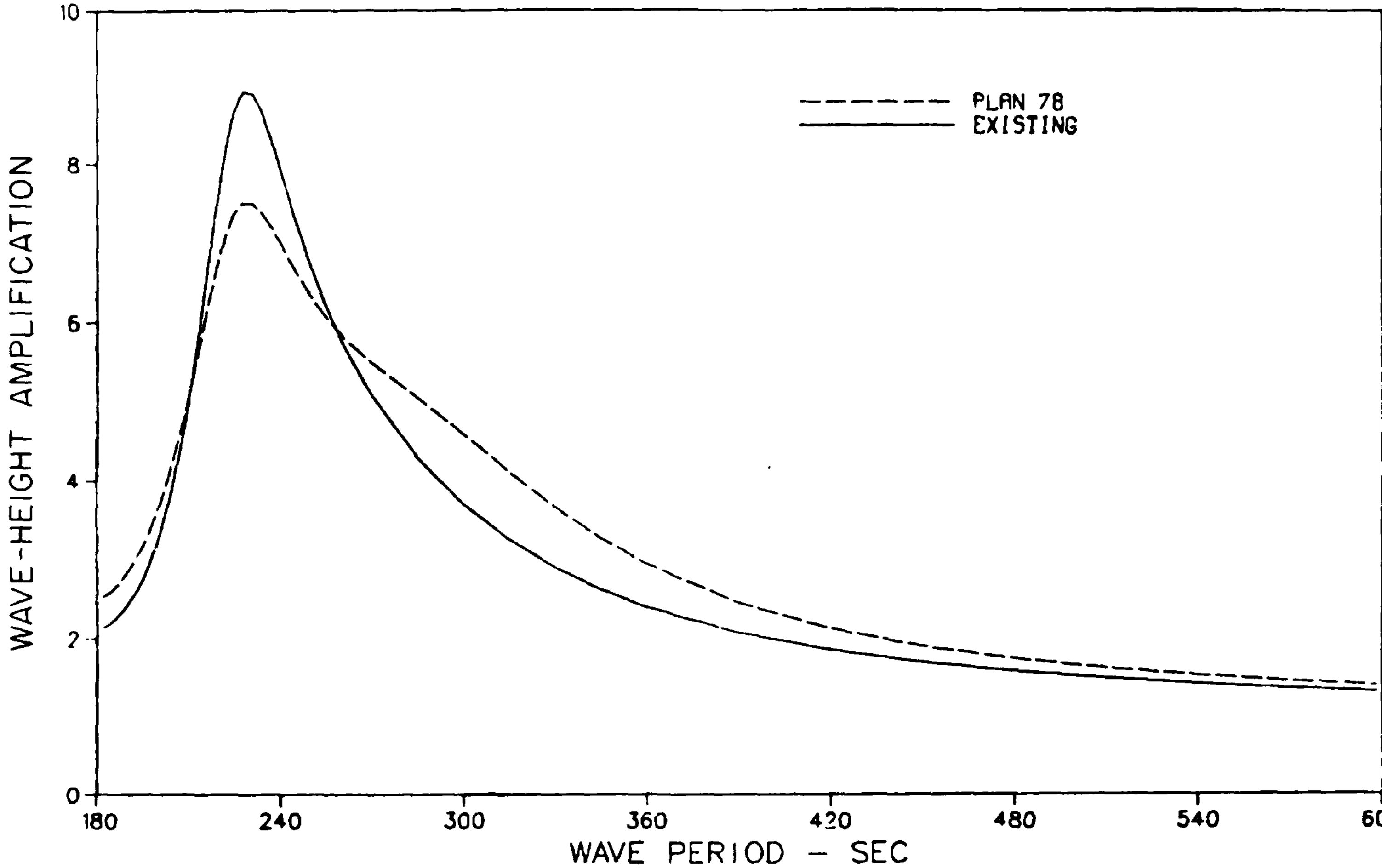
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 12
30- TO 180-SEC WAVE PERIODS



FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 12
180- TO 600-SEC WAVE PERIODS

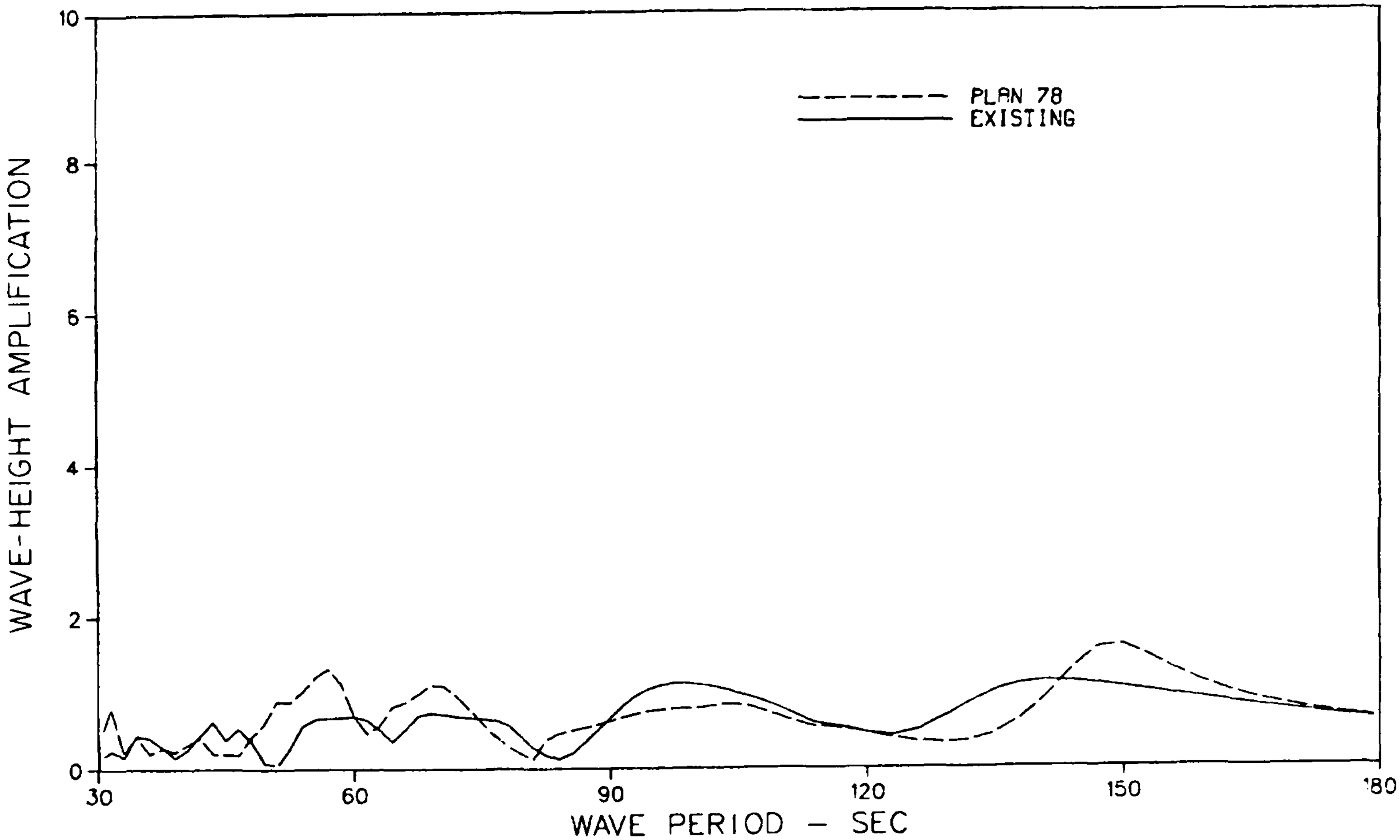


FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 15
30- TO 180-SEC WAVE PERIODS

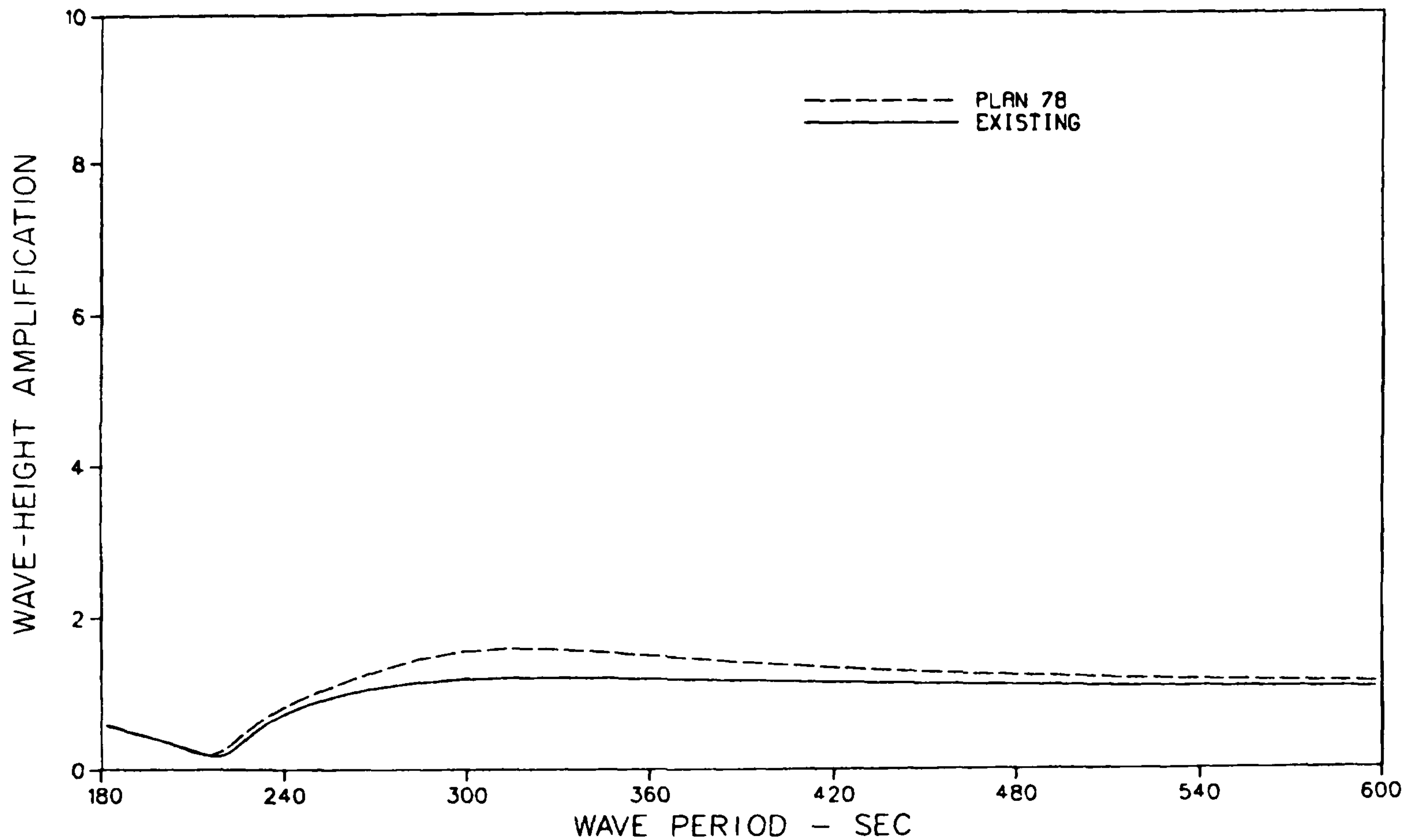


FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 15
180- TO 600- SEC WAVE PERIODS

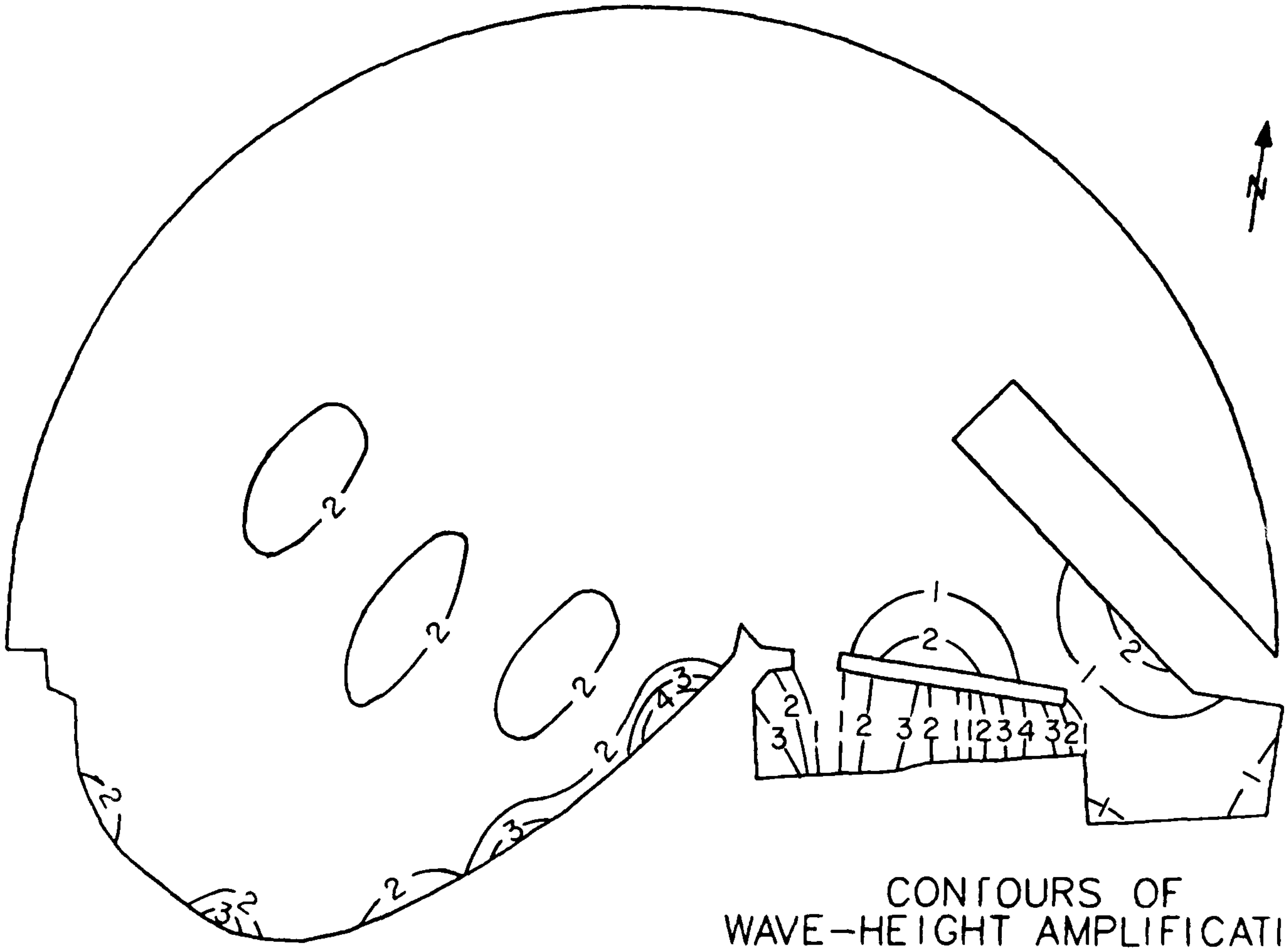
PLATE 52



FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 4A
30- TO 180-SEC WAVE PERIODS

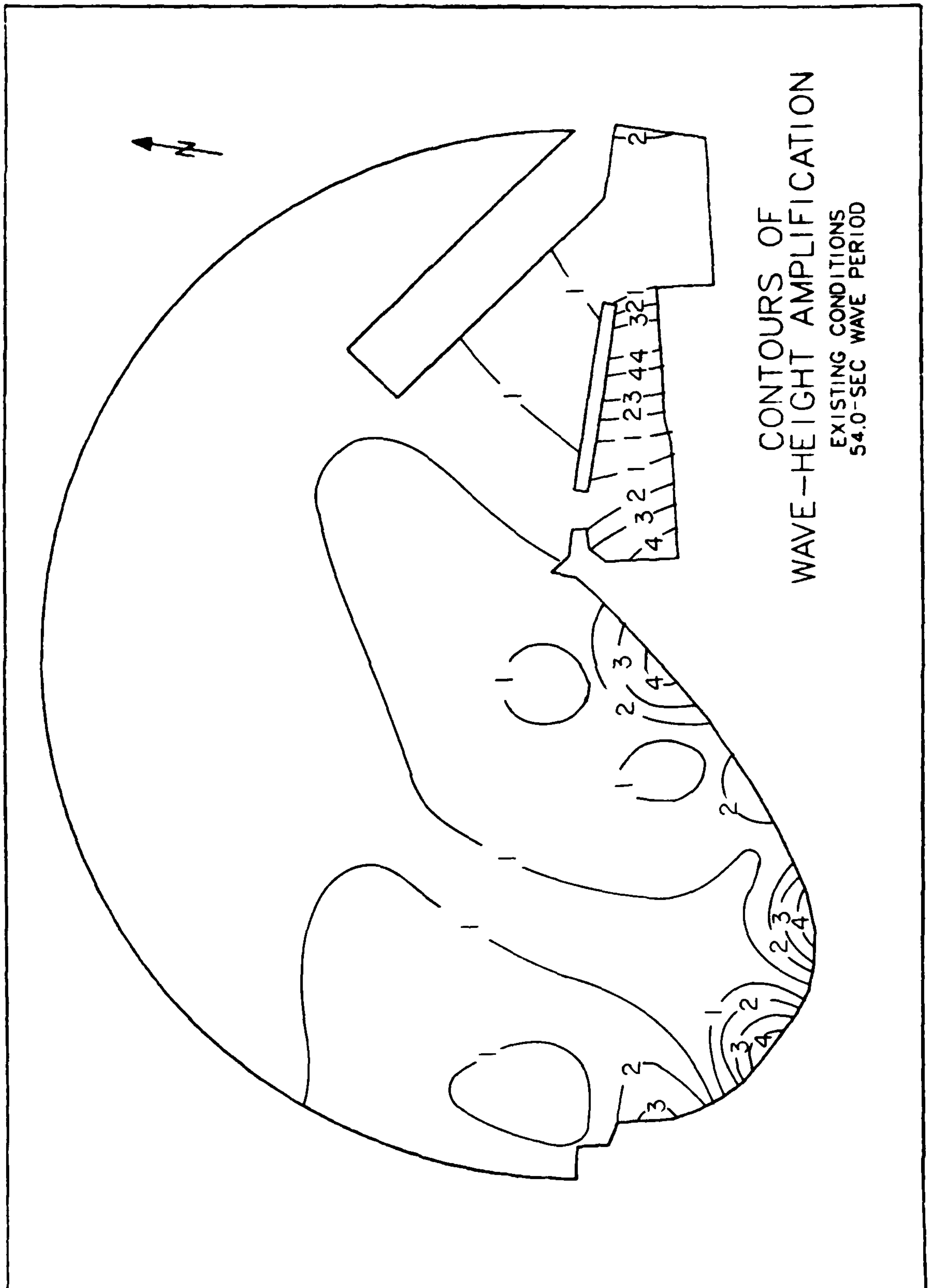


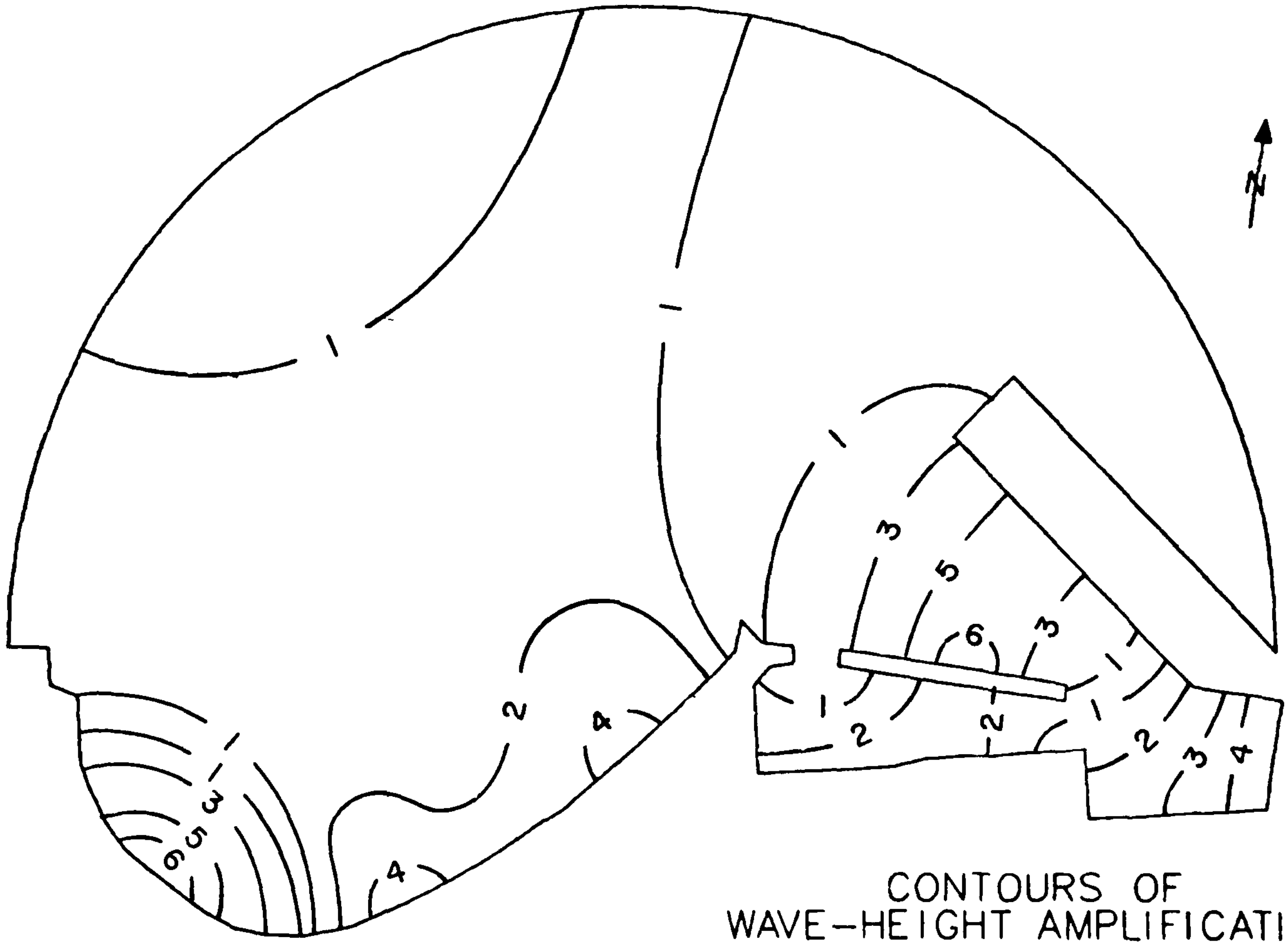
FREQUENCY RESPONSE
WAVE-HEIGHT AMPLIFICATION
STATION 4A
180- TO 600-SEC WAVE PERIODS



CONTOURS OF
WAVE-HEIGHT AMPLIFICATION

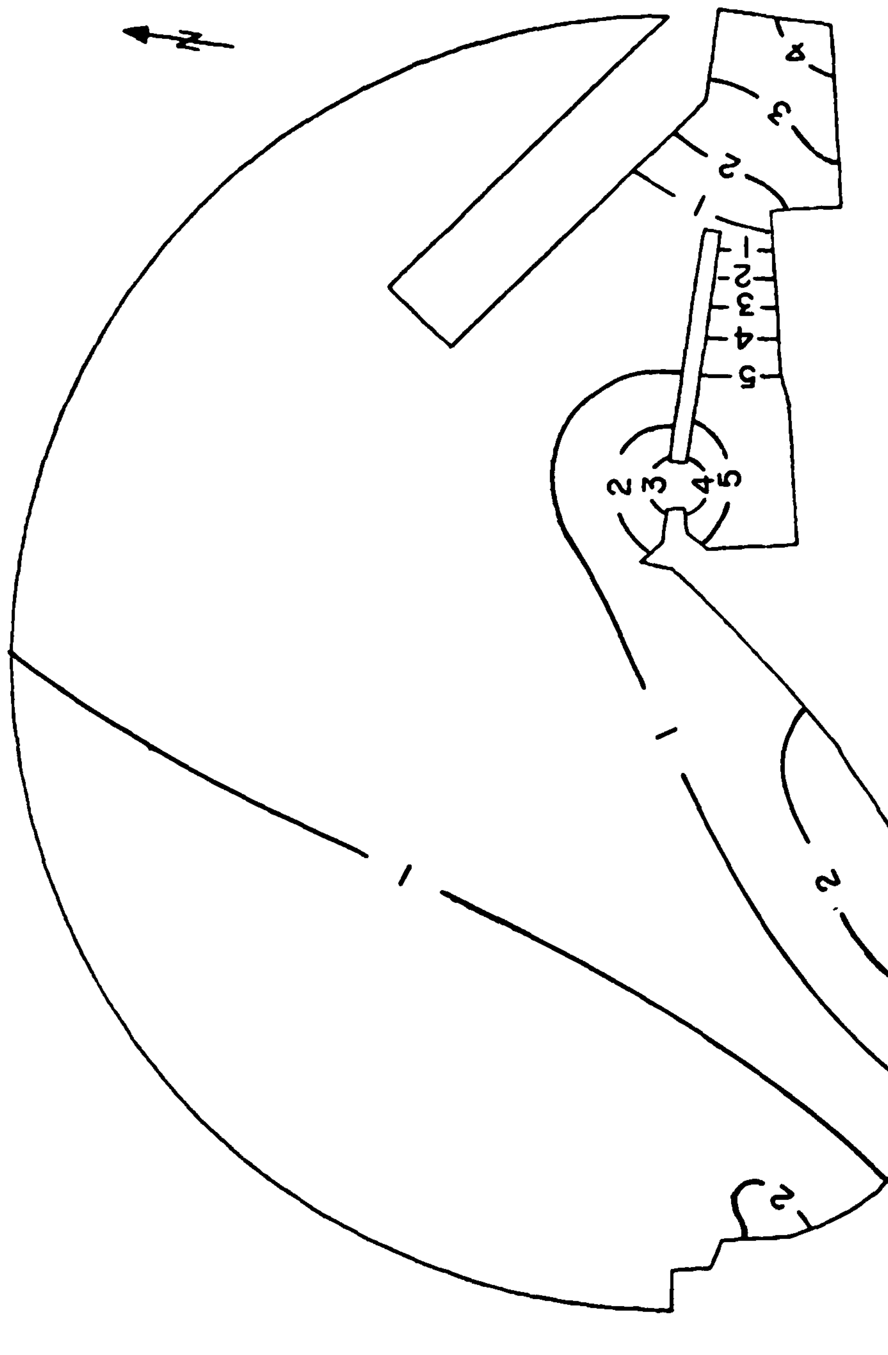
EXISTING CONDITIONS
34.5-SEC WAVE PERIOD


CONTOURS OF
WAVE-HEIGHT AMPLIFICATION
EXISTING CONDITIONS
54.0-SEC WAVE PERIOD

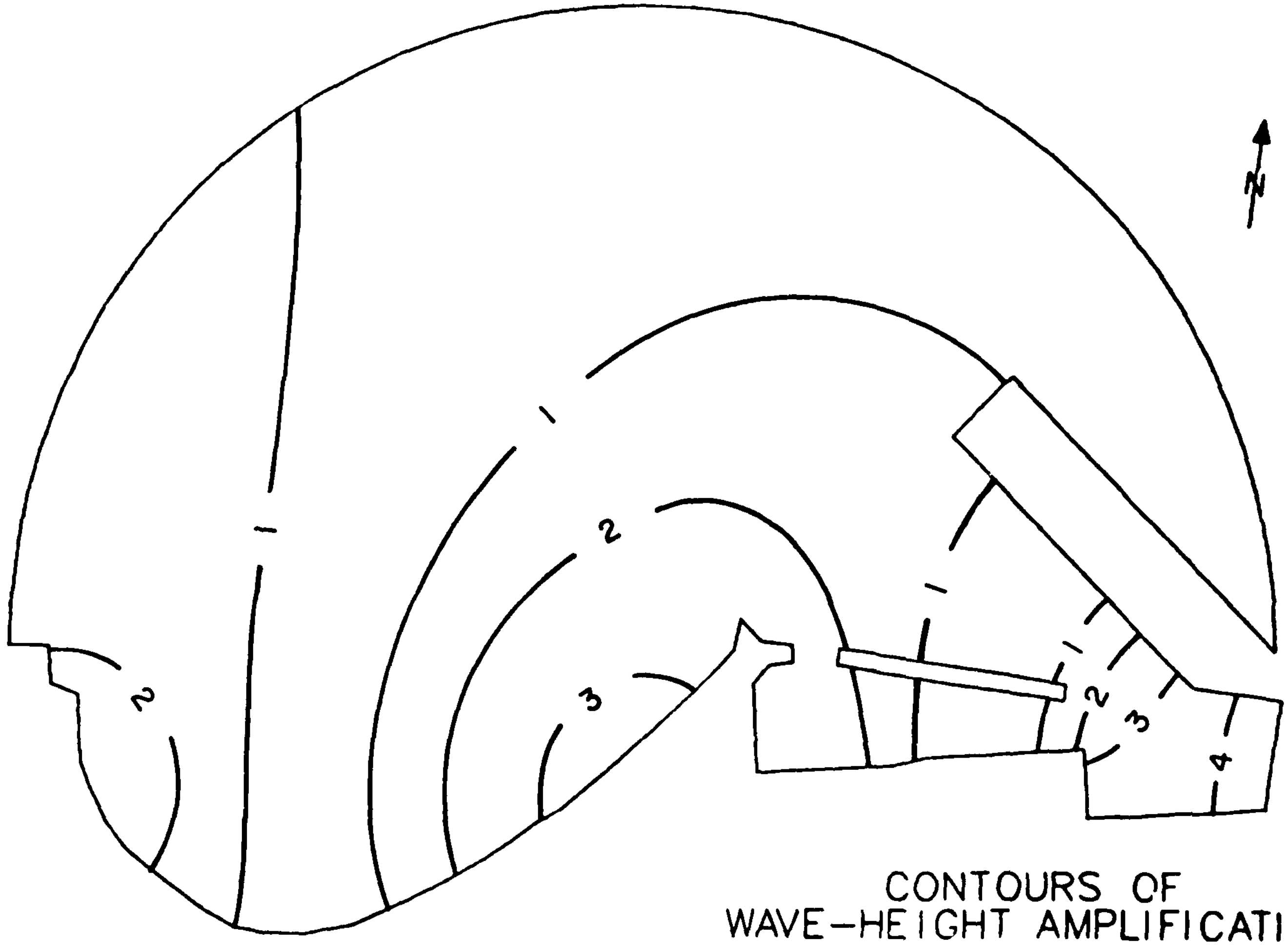


CONTOURS OF
WAVE-HEIGHT AMPLIFICATION

EXISTING CONDITIONS
79.5-SEC WAVE PERIOD

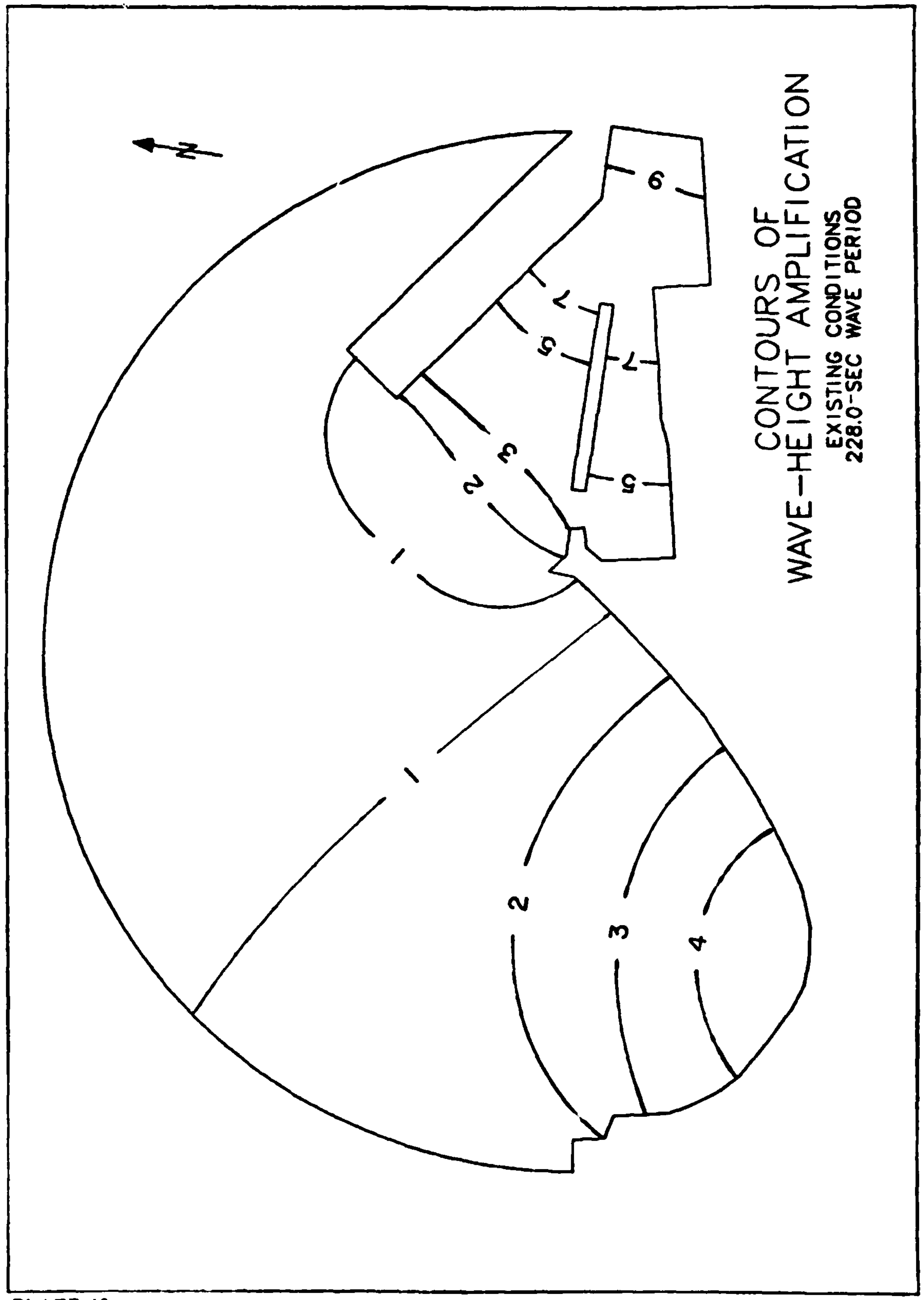


CONTOURS OF
WAVE-HEIGHT AMPLIFICATION
EXISTING CONDITIONS
115.5-SEC WAVE PERIOD

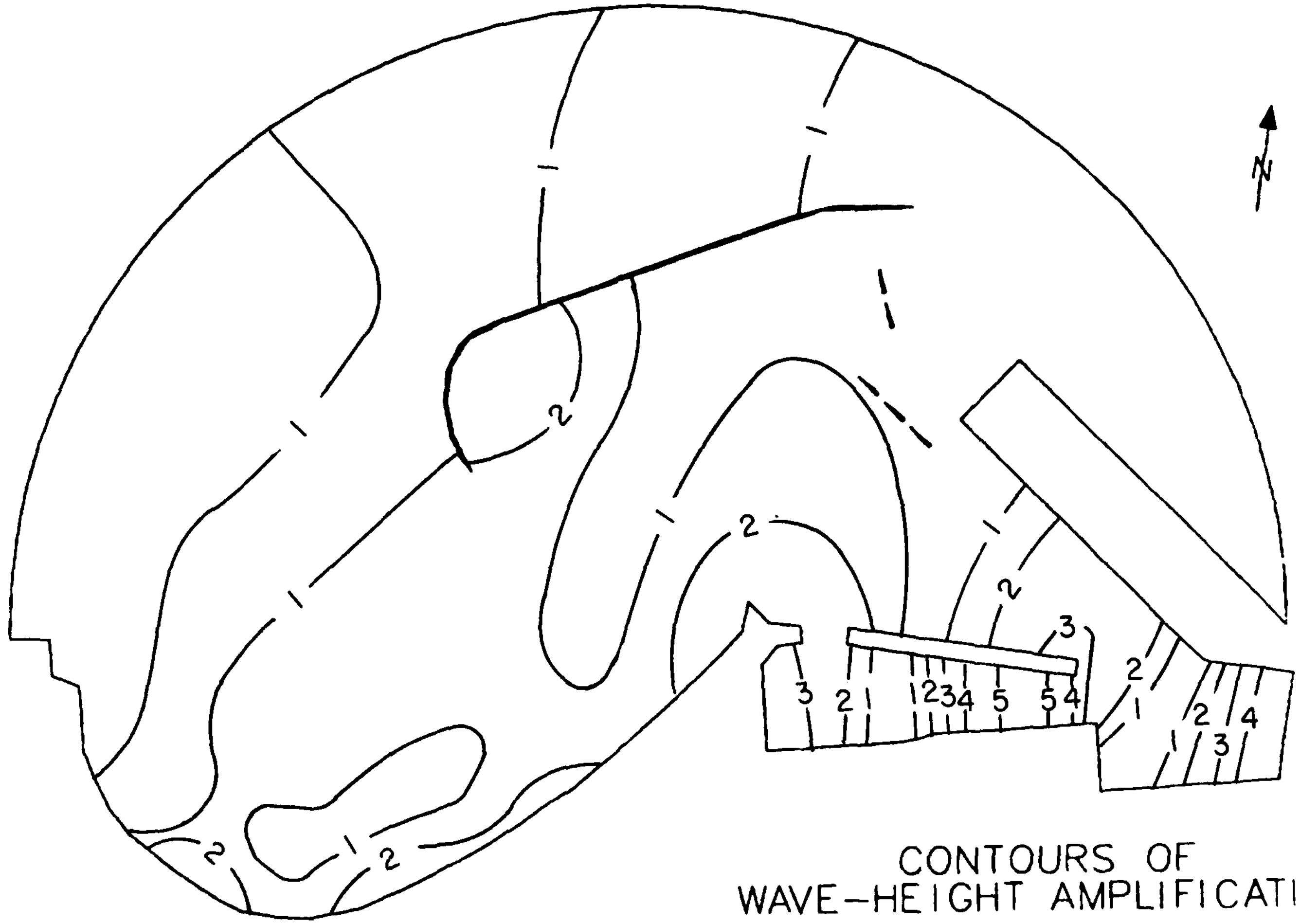


CONTOURS OF
WAVE-HEIGHT AMPLIFICATION

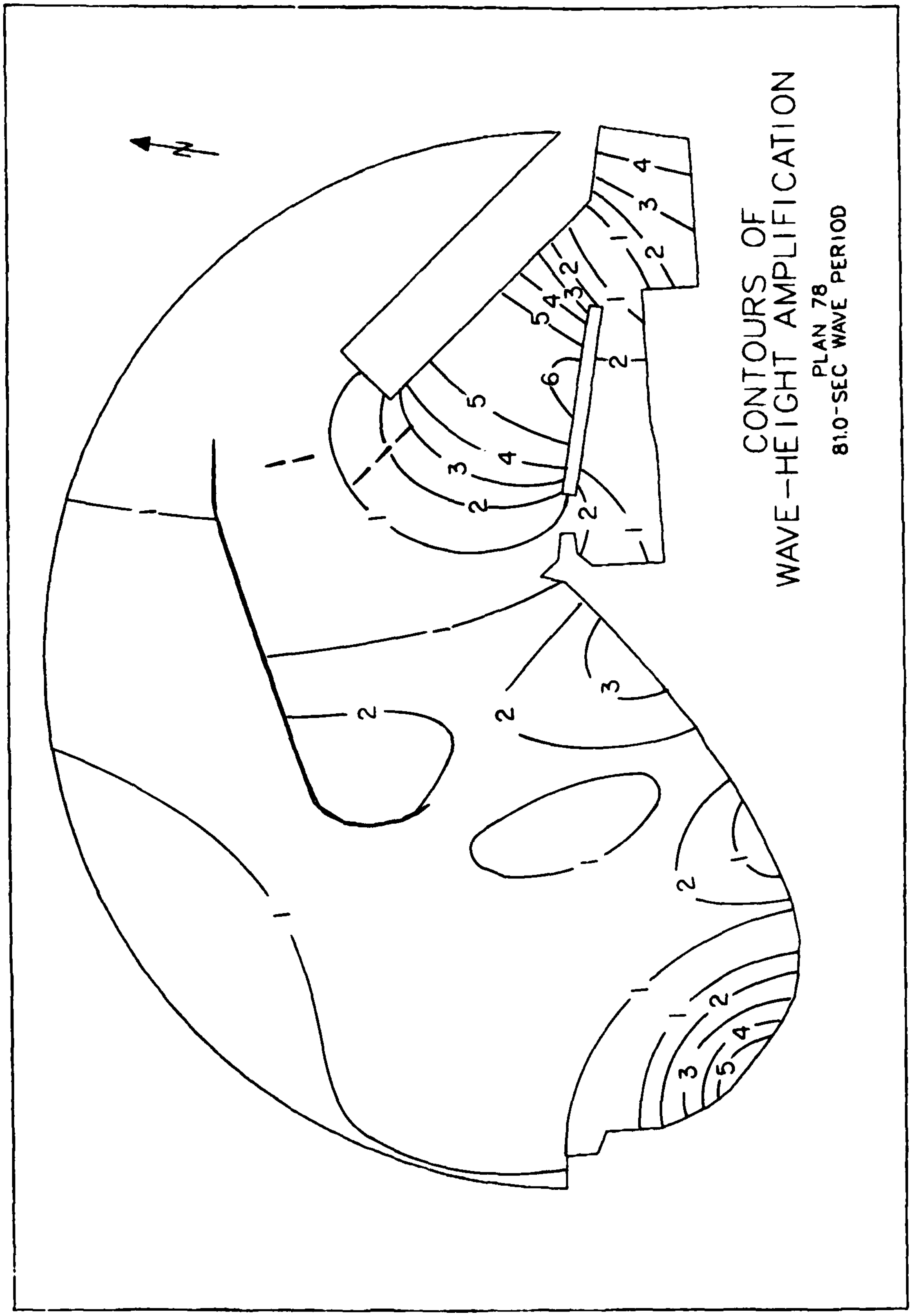
EXISTING CONDITIONS
135.0-SEC WAVE PERIOD



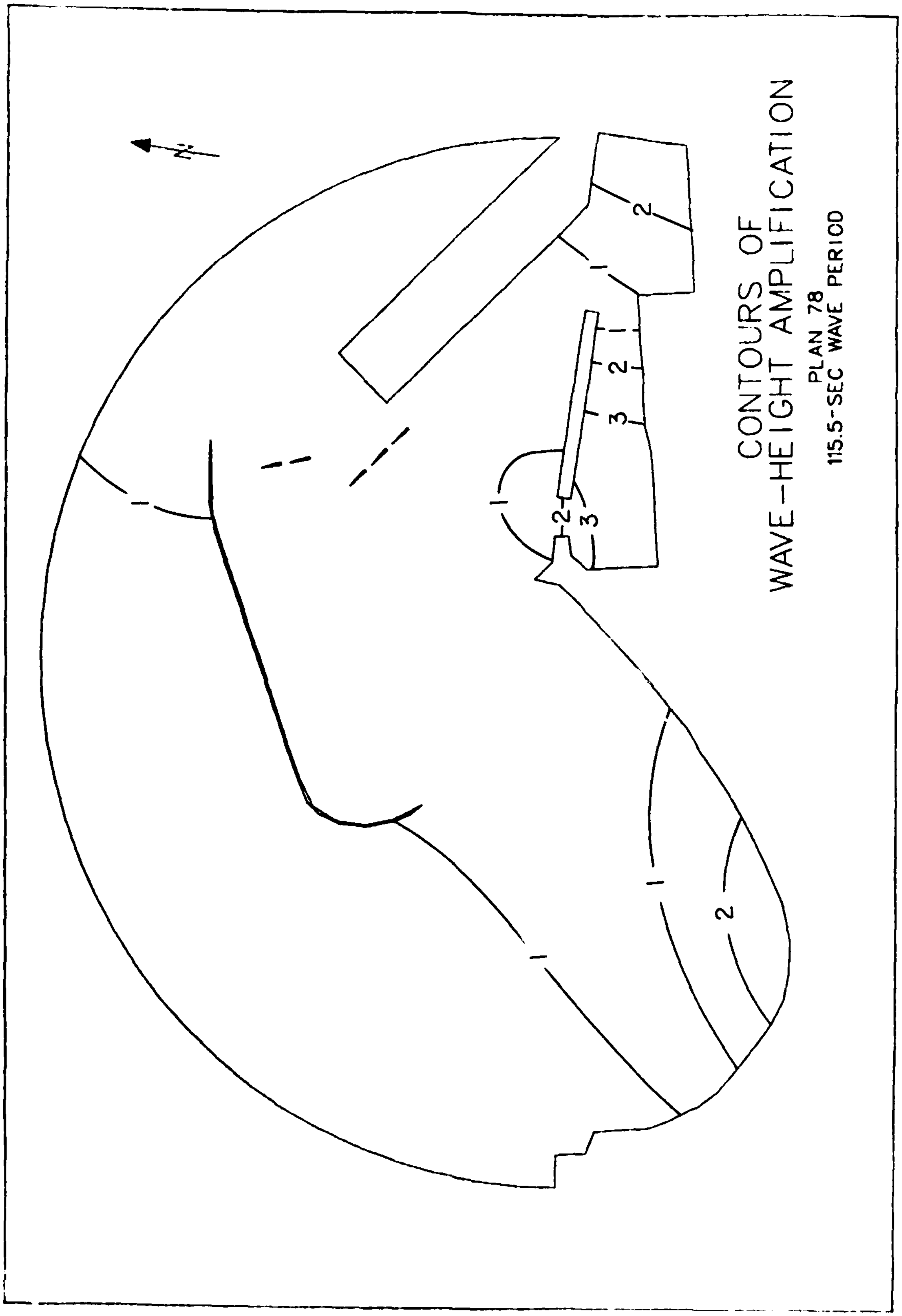
CONTOURS OF
WAVE-HEIGHT AMPLIFICATION
EXISTING CONDITIONS
228.0-SEC WAVE PERIOD



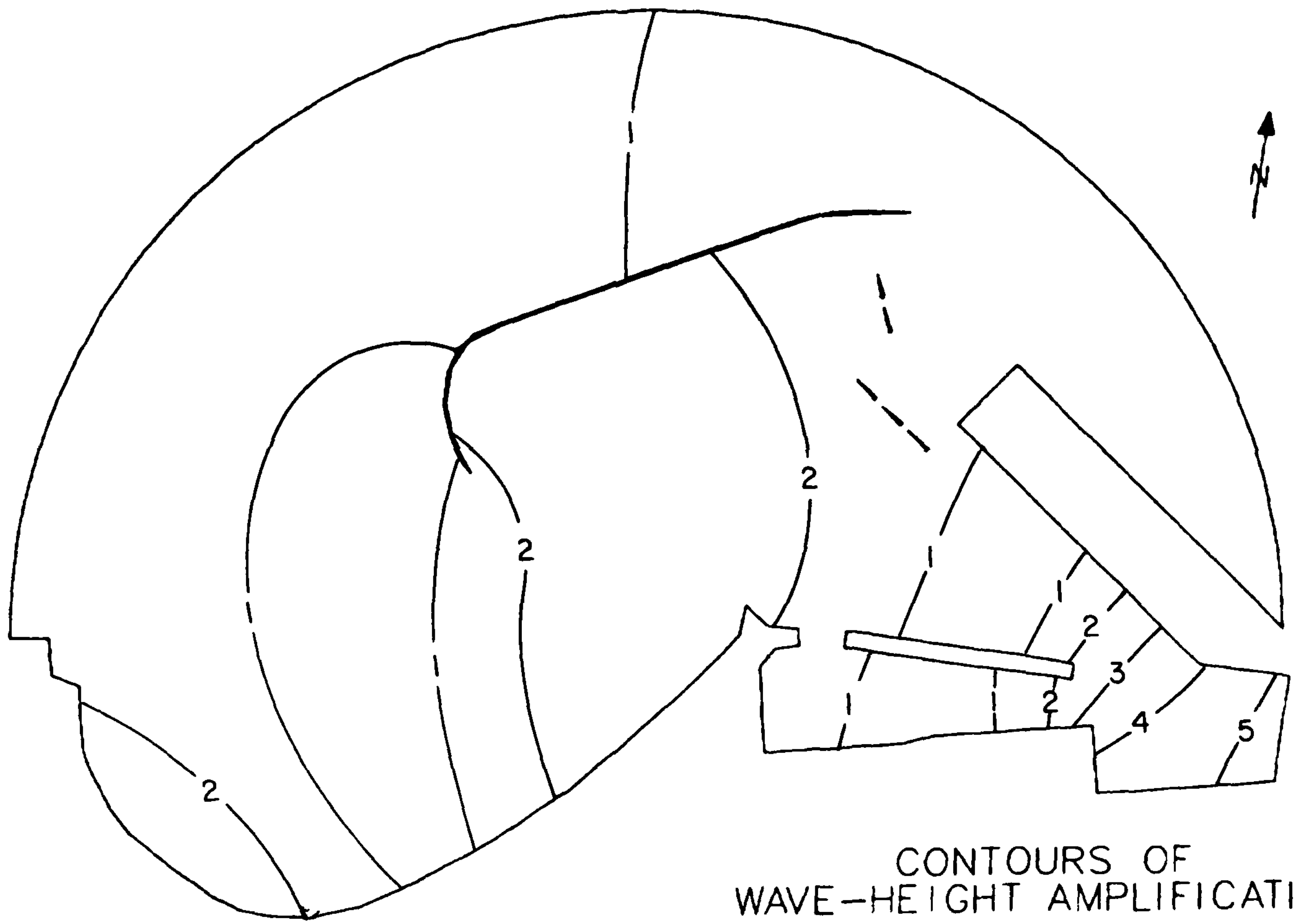
CONTOURS OF
WAVE-HEIGHT AMPLIFICATION
PLAN 78
63.0-SEC WAVE PERIOD



CONTOURS OF
WAVE-HEIGHT AMPLIFICATION
PLAN 78
81.0-SEC WAVE PERIOD

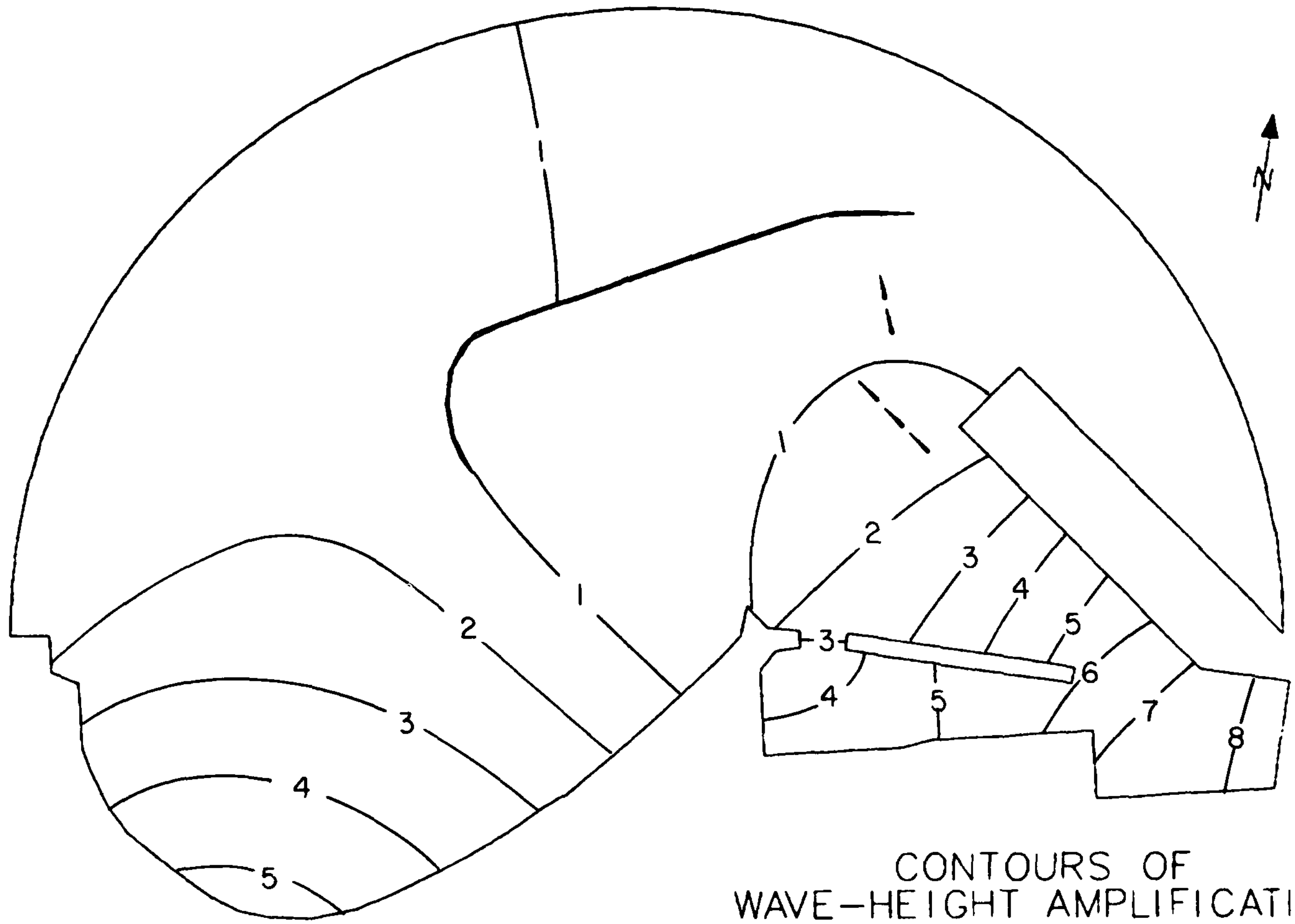


CONTOURS OF
WAVE-HEIGHT AMPLIFICATION
PLAN 78
115.5-SEC WAVE PERIOD



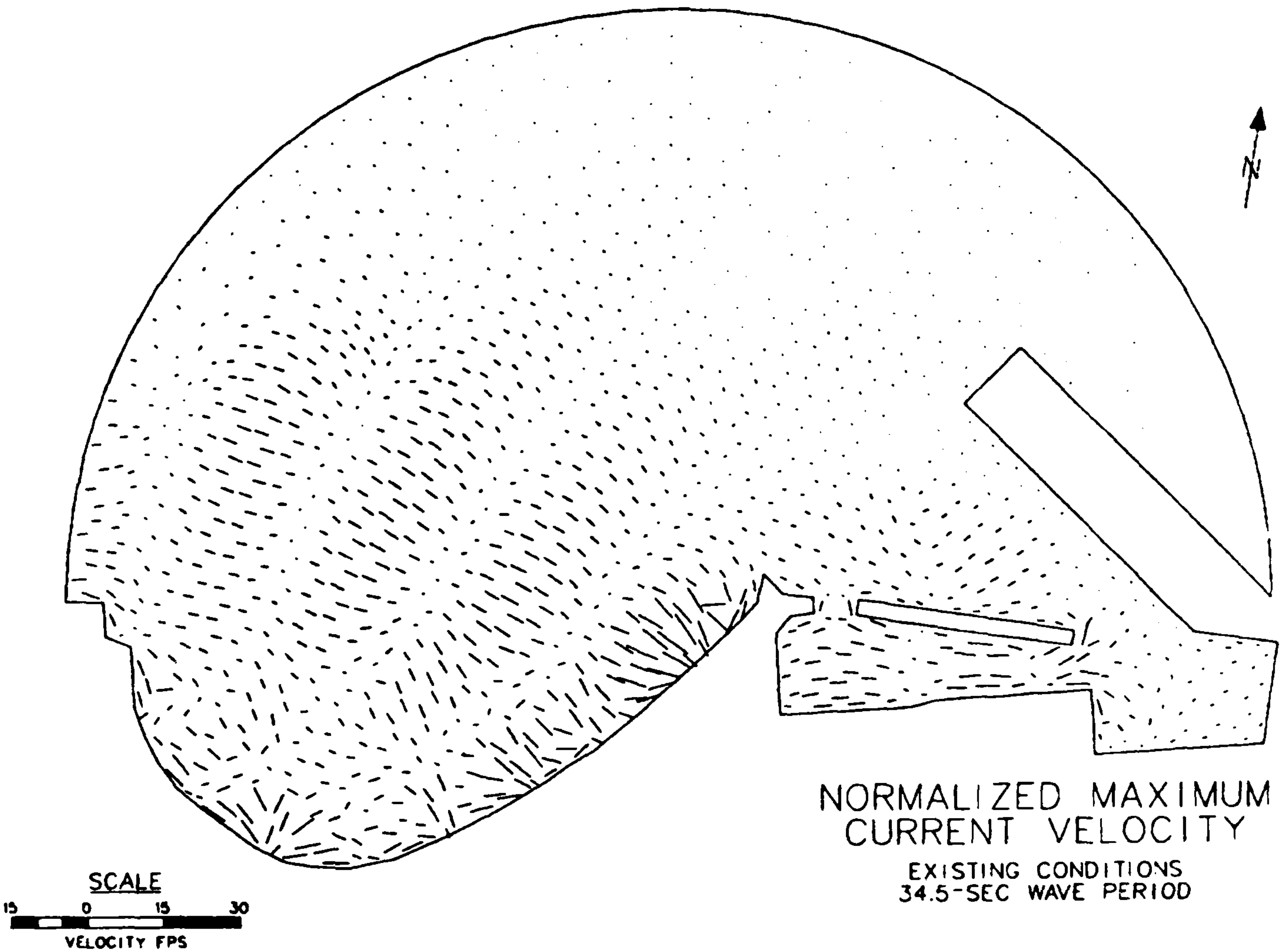
CONTOURS OF
WAVE-HEIGHT AMPLIFICATION

PLAN 78
147.0-SEC WAVE PERIOD



CONTOURS OF
WAVE-HEIGHT AMPLIFICATION

PLAN 78
228.0-SEC WAVE PERIOD



NORMALIZED MAXIMUM CURRENT VELOCITY

EXISTING CONDITIONS
34.5-SEC WAVE PERIOD

PLATE 66

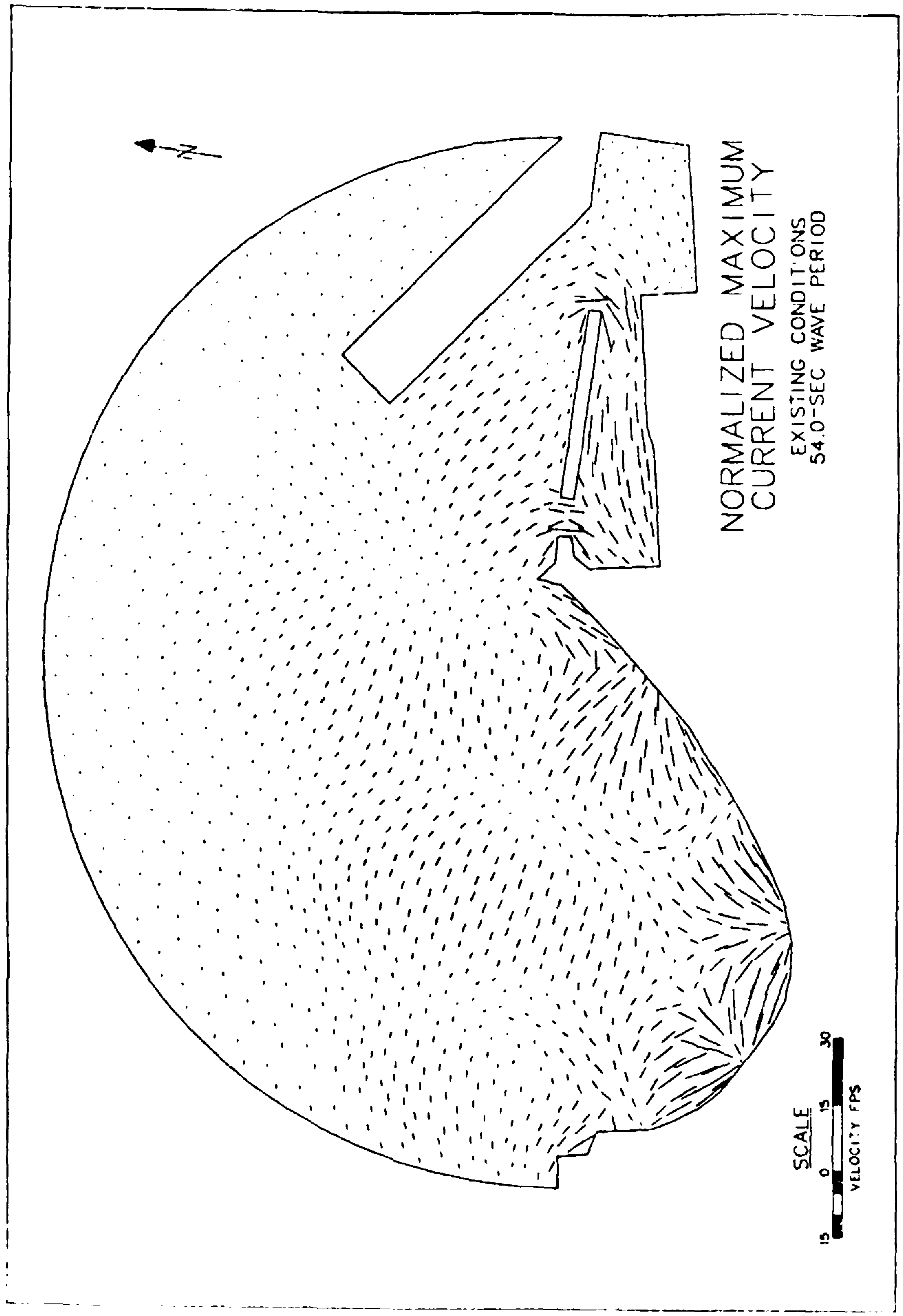
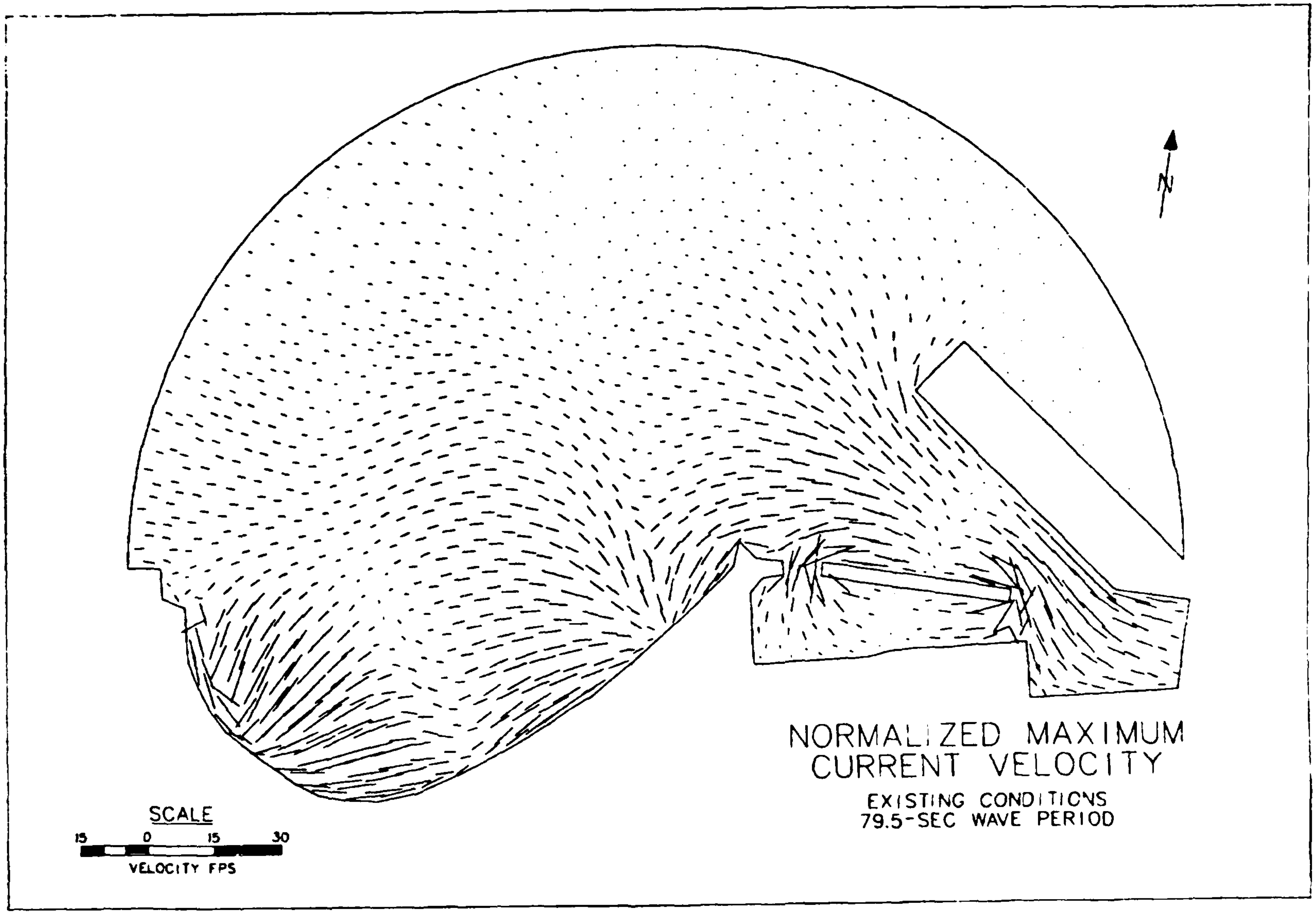

NORMALIZED MAXIMUM
CURRENT VELOCITY
EXISTING CONDITIONS
54.0-SEC WAVE PERIOD
SCALE
15 0 15 30
VELOCITY FPS
N

PLATE 67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NORMALIZED MAXIMUM
CURRENT VELOCITY
EXISTING CONDITIONS
79.5-SEC WAVE PERIOD
SCALE
15 0 15 30
VELOCITY FPS

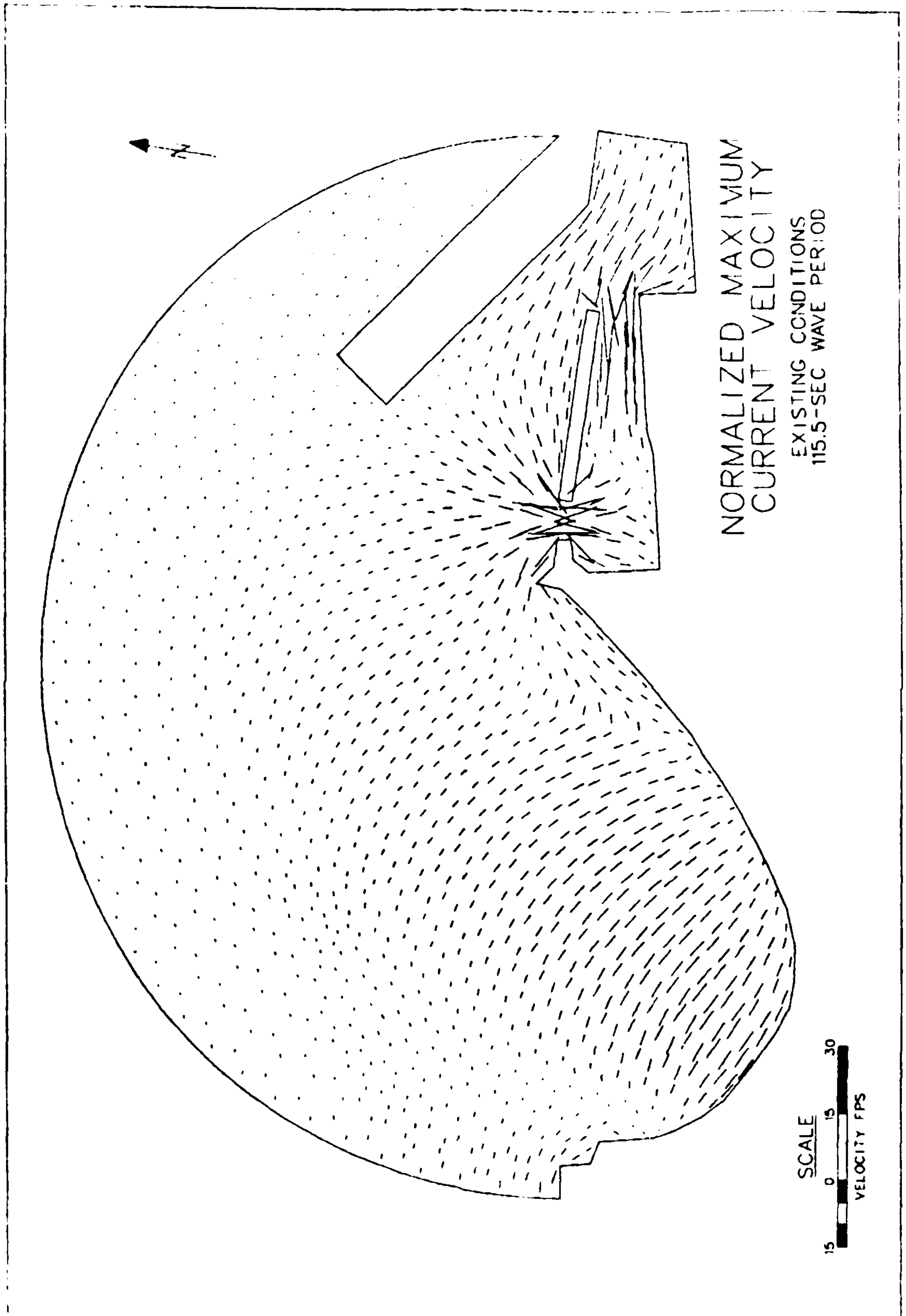
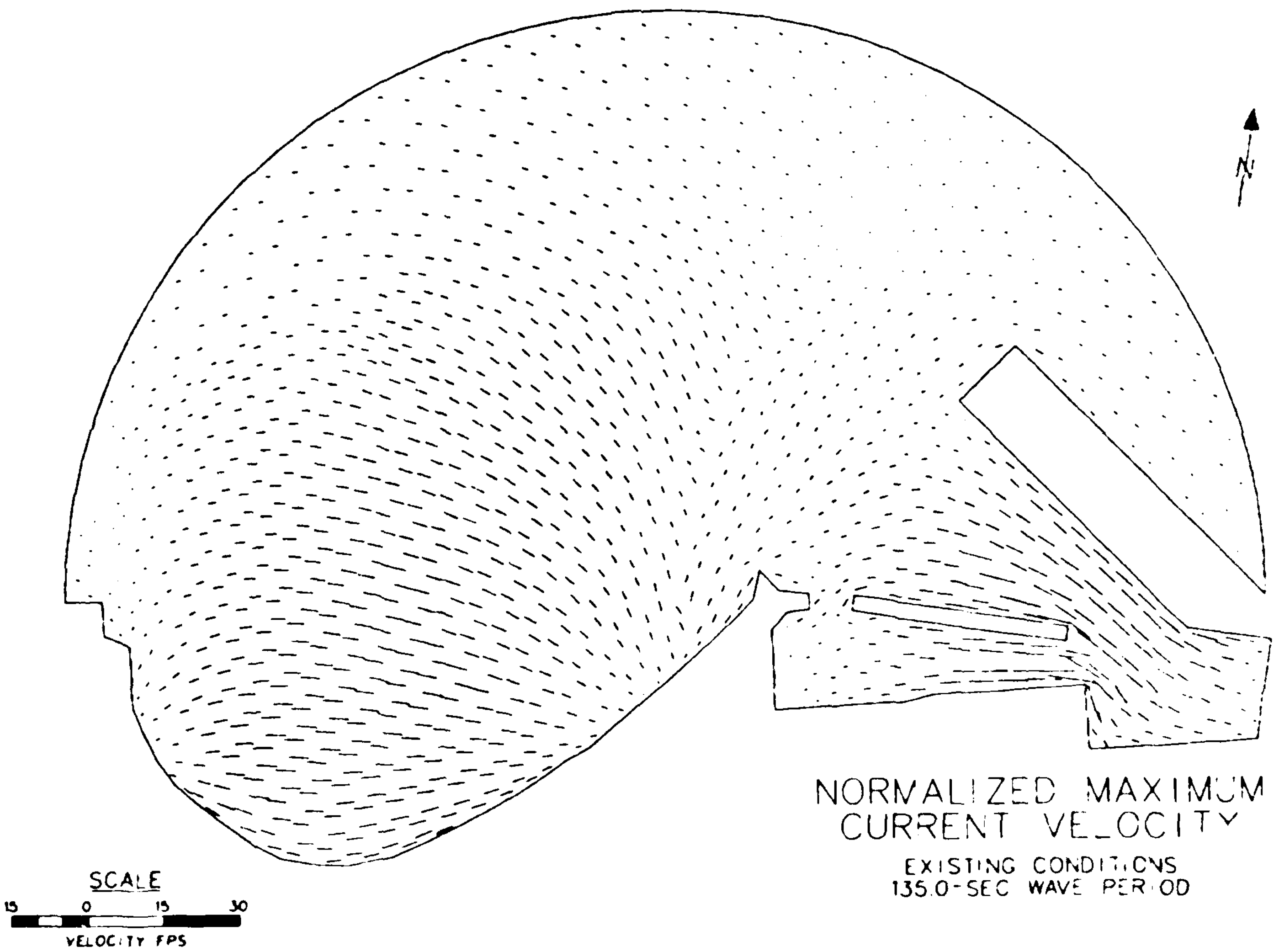
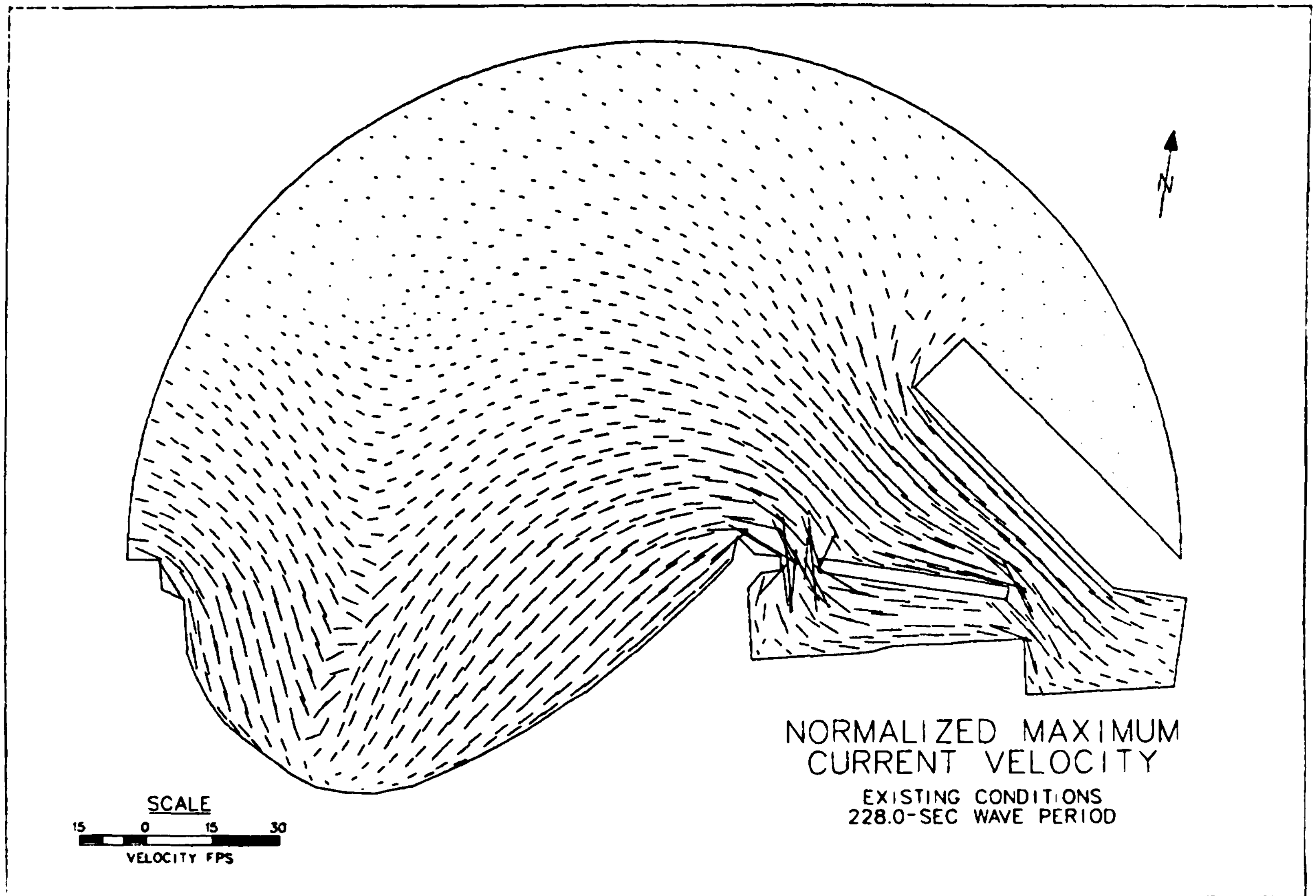

NORMALIZED MAXIMUM
CURRENT VELOCITY
EXISTING CONDITIONS
115.5-SEC WAVE PERIOD
N
SCALE
15 0 15 30
VELOCITY FPS

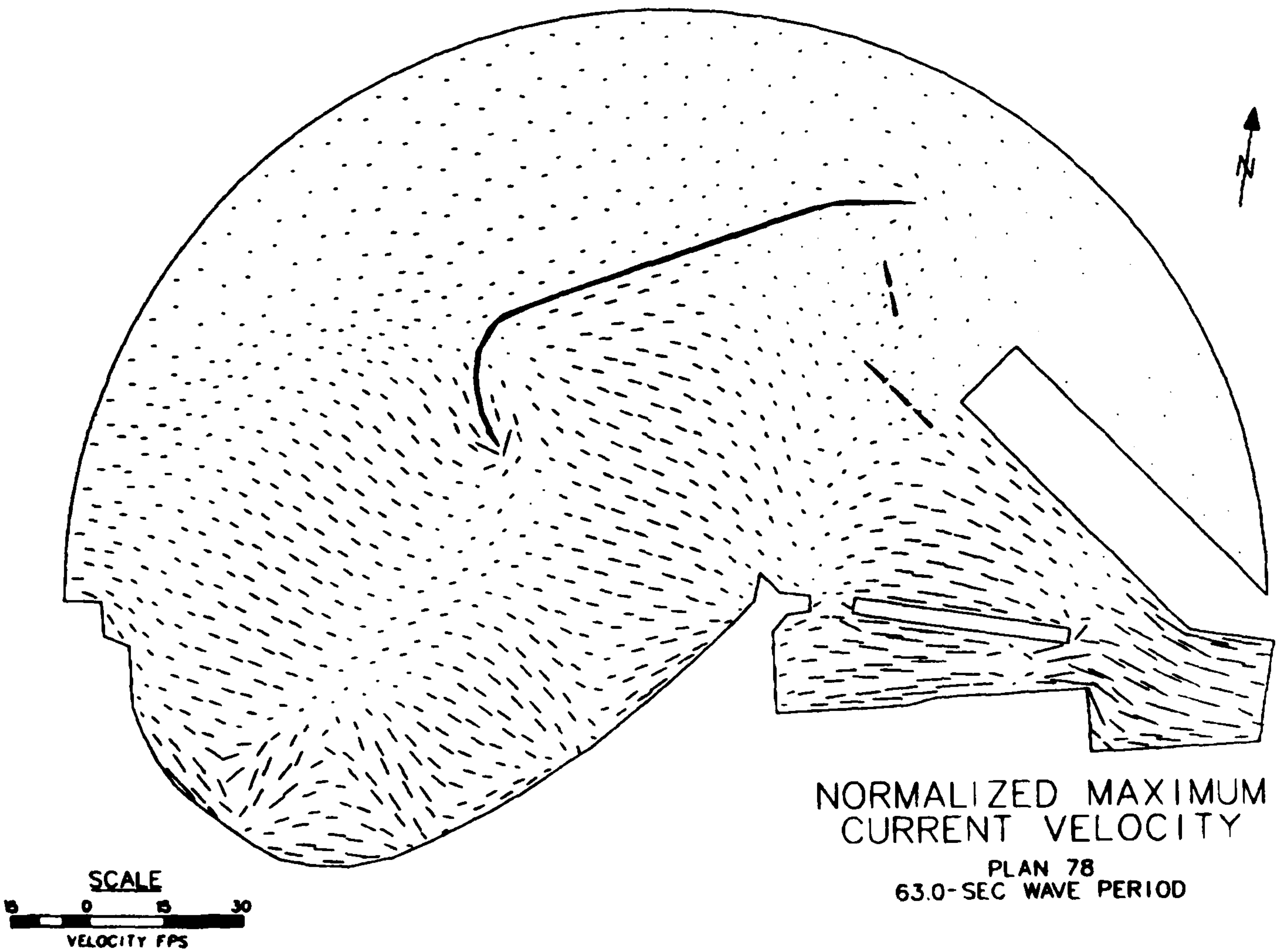
PLATE 69



NORMALIZED MAXIMUM CURRENT VELOCITY

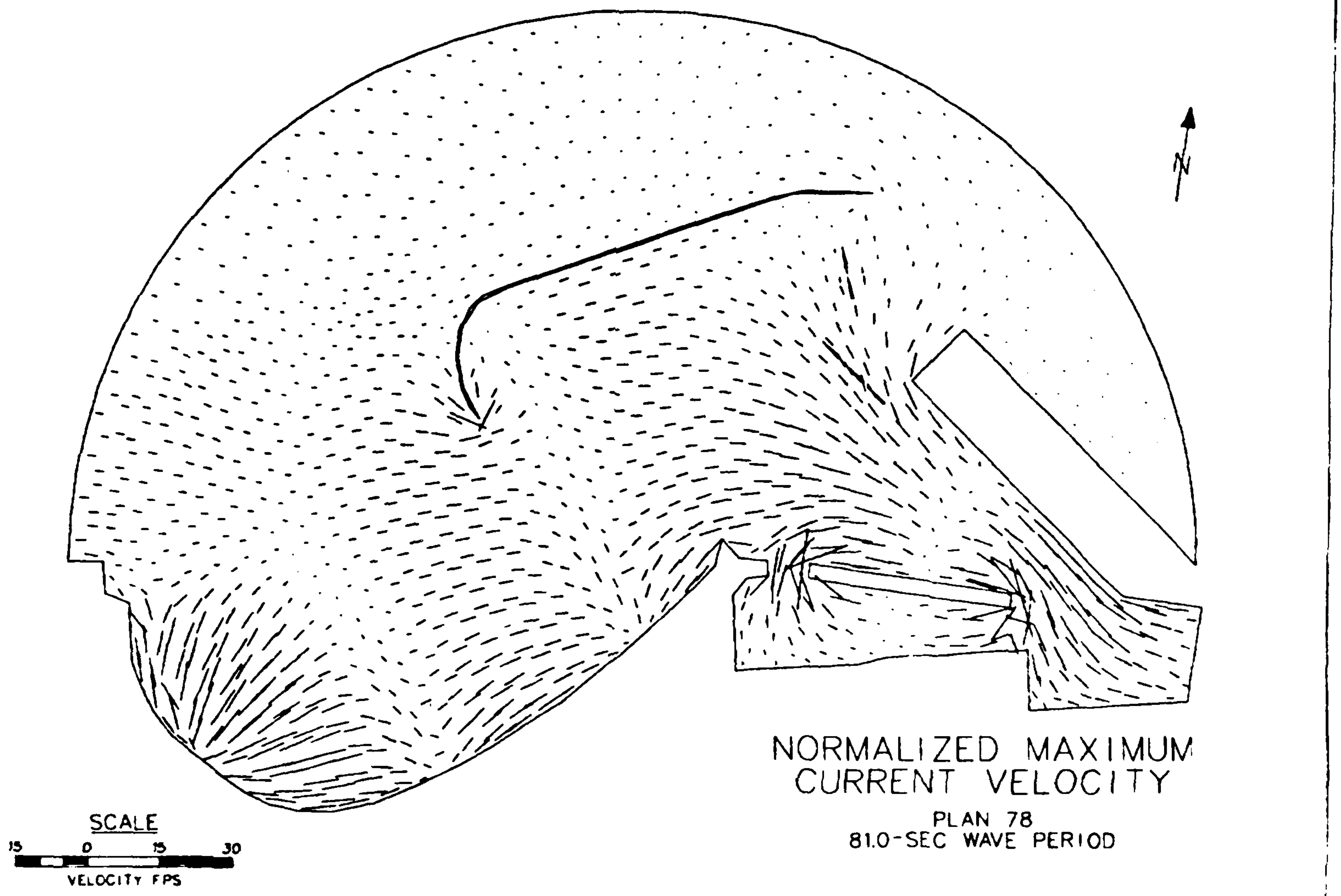
EXISTING CONDITIONS
135.0-SEC WAVE PERIOD


N
NORMALIZED MAXIMUM
CURRENT VELOCITY
EXISTING CONDITIONS
228.0-SEC WAVE PERIOD
SCALE
15 0 15 30
VELOCITY FPS



NORMALIZED MAXIMUM
CURRENT VELOCITY

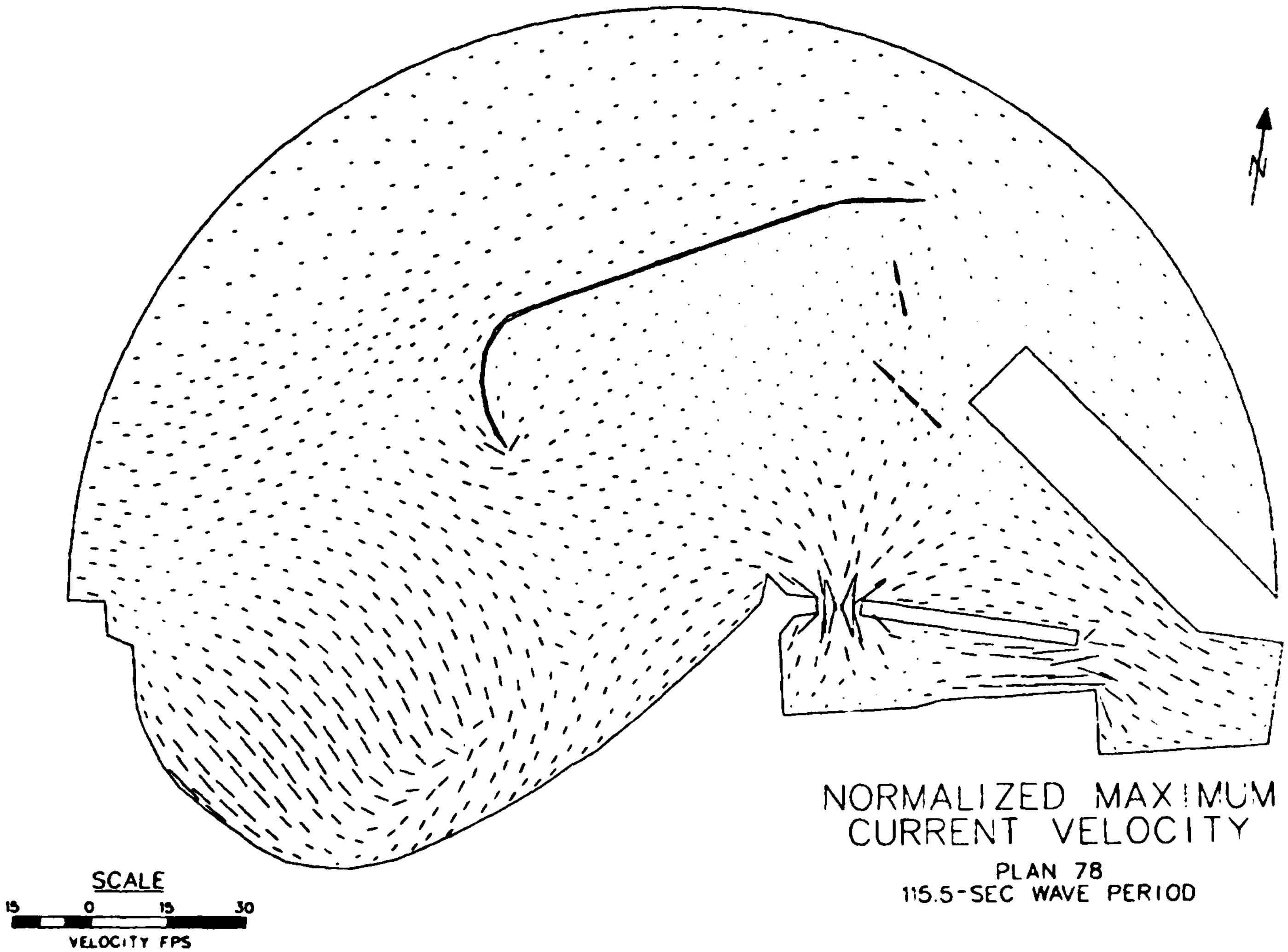
PLAN 78
63.0-SEC WAVE PERIOD



NORMALIZED MAXIMUM CURRENT VELOCITY

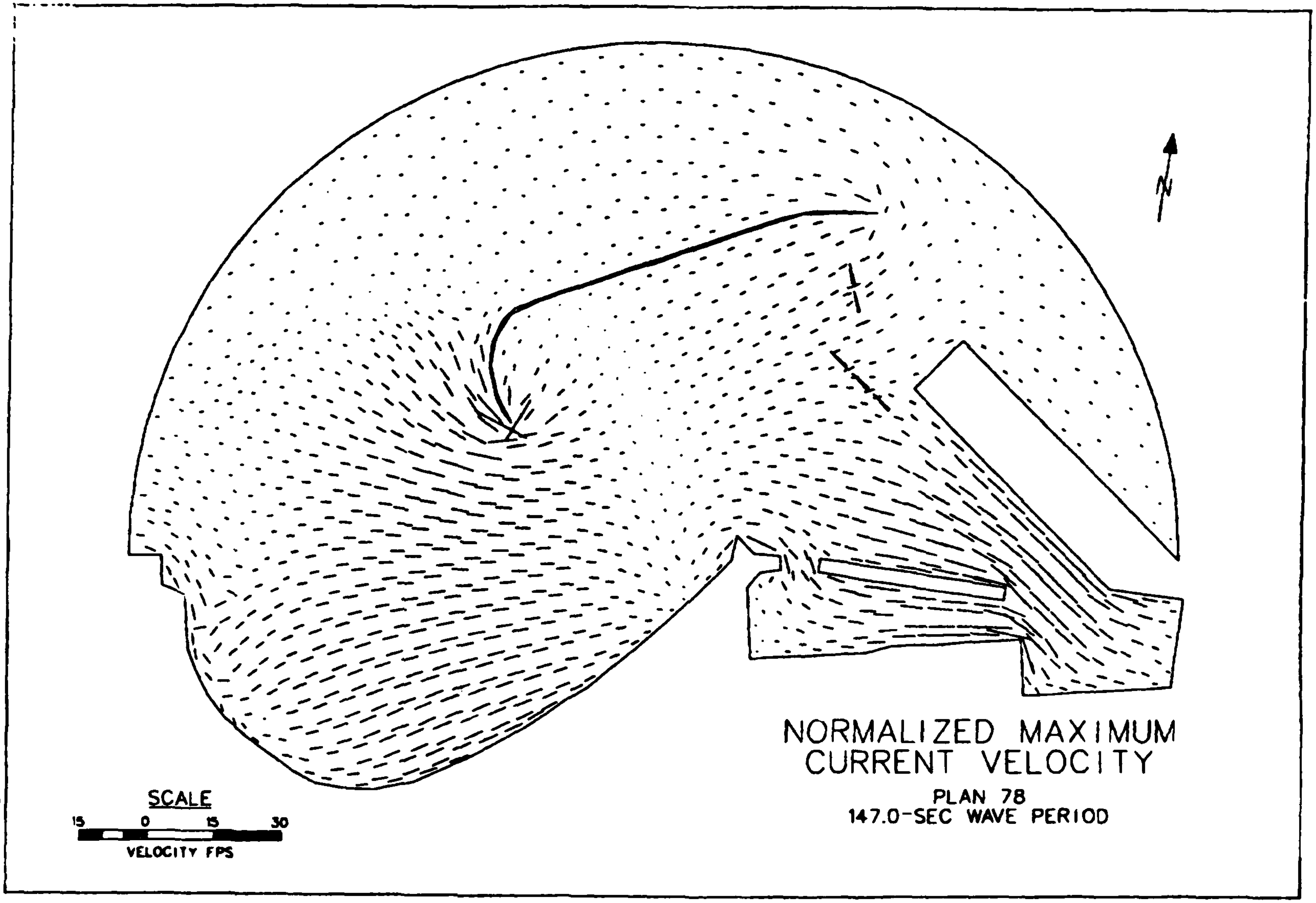
PLAN 78
81.0-SEC WAVE PERIOD

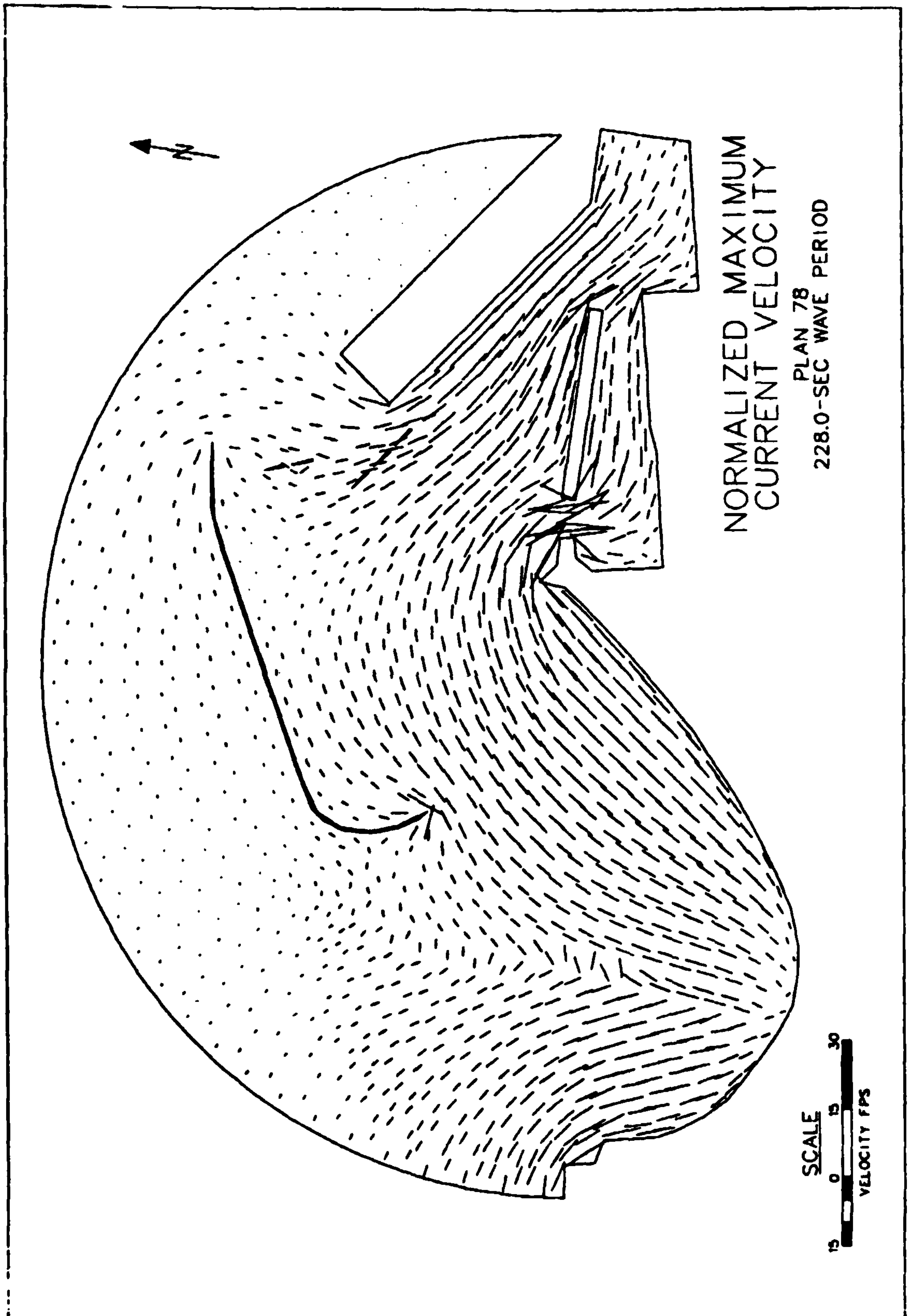
PLATE 74



NORMALIZED MAXIMUM
CURRENT VELOCITY

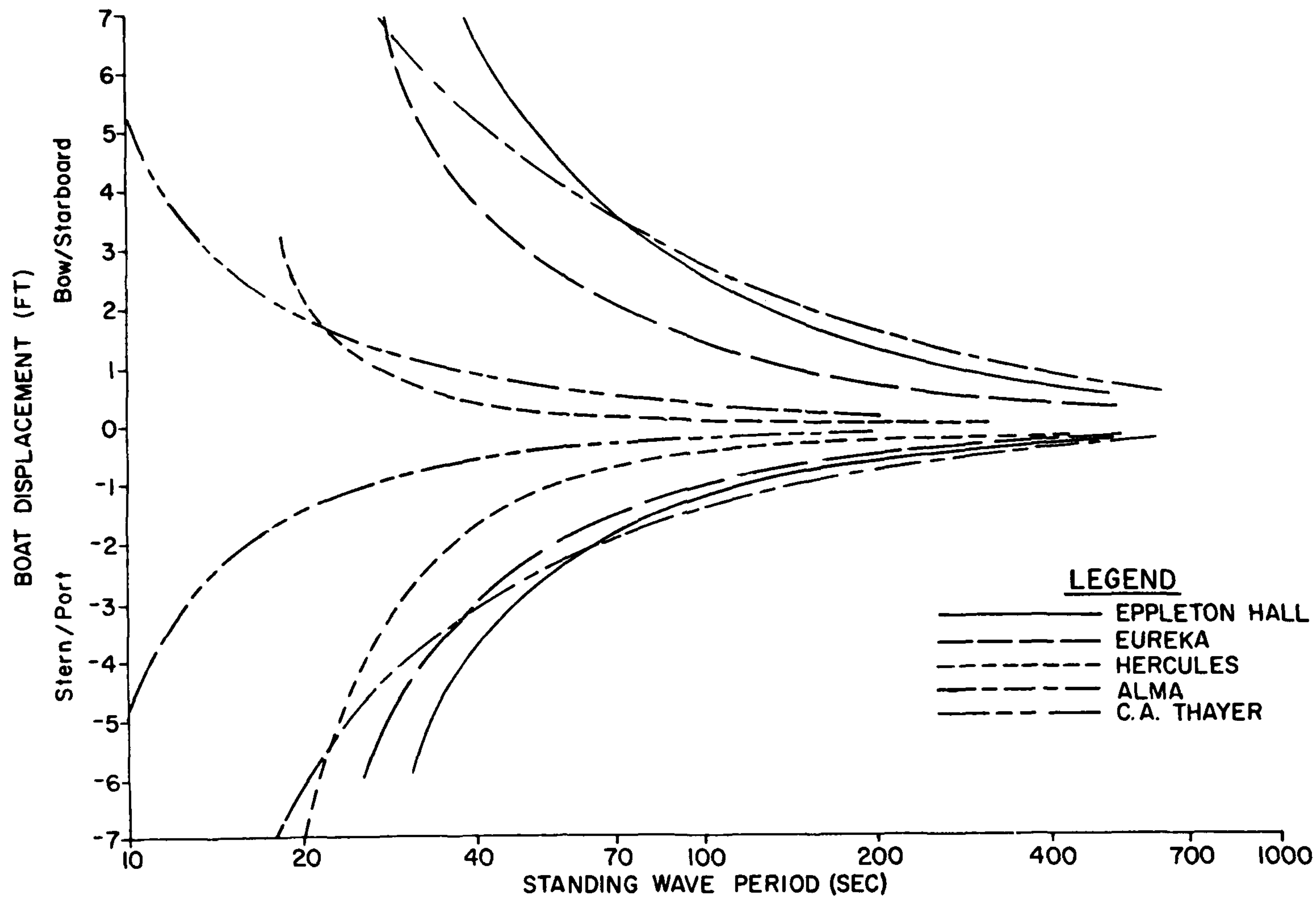
PLAN 78
115.5-SEC WAVE PERIOD


NORMALIZED MAXIMUM
CURRENT VELOCITY
PLAN 78
147.0-SEC WAVE PERIOD
SCALE
15 0 15 30
VELOCITY FPS

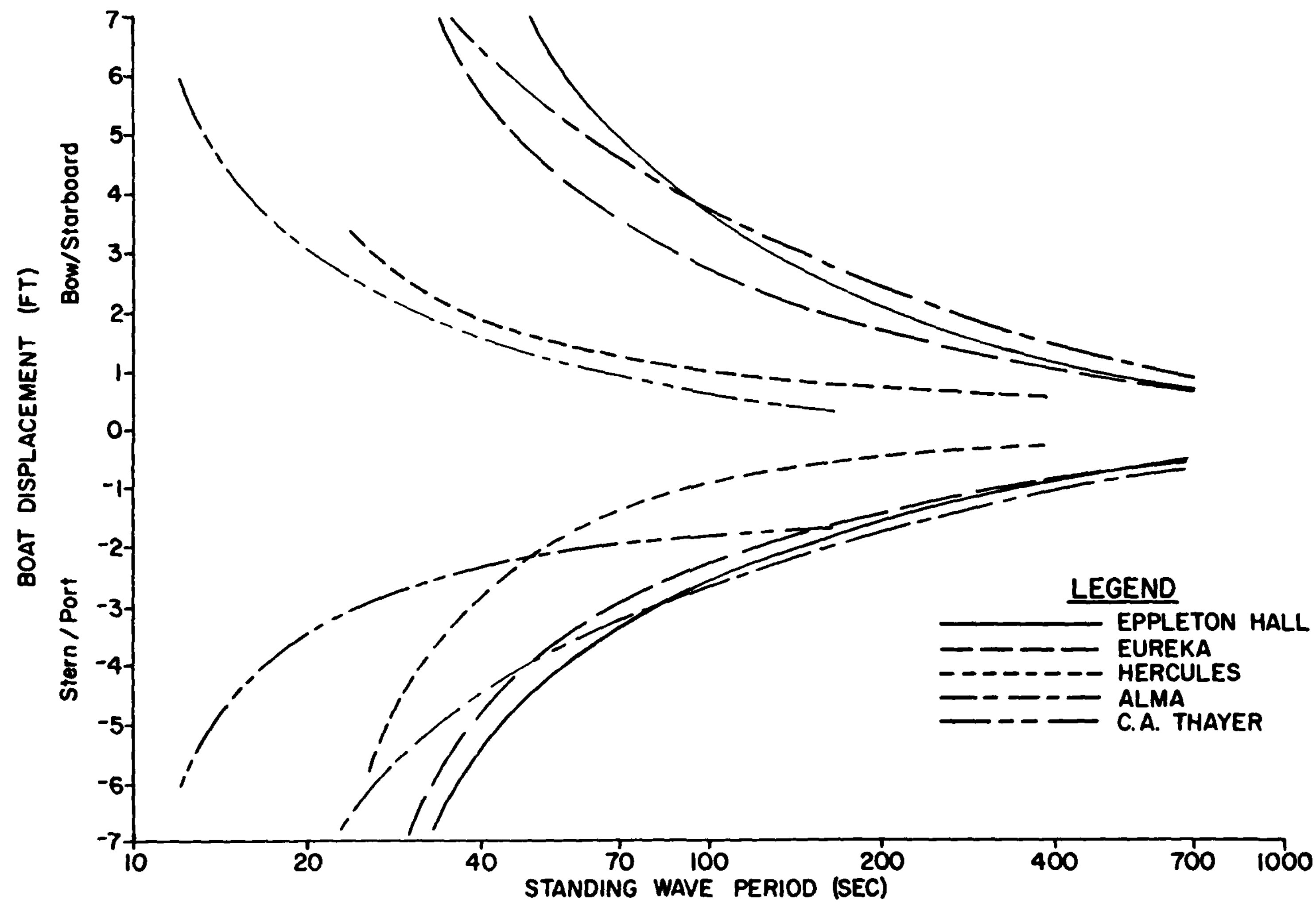


NORMALIZED MAXIMUM
CURRENT VELOCITY

PLAN 7B
228.0-SEC WAVE PERIOD



BOAT DISPLACEMENT VS. STANDING WAVE PERIOD: NO SLACK



BOAT DISPLACEMENT VS. STANDING WAVE PERIOD: 1-FT SLACK

PLATE 78

APPENDIX A: NOTATION

a	Boundary of region, standing wave amplitude
a_o	Incident wave amplitude
A	Area
A_r	Region inside harbor
$b(\omega)$	Amplitude of frequency component ω
b	Distance from reflecting surface to center of ship
b_a	Incident wave amplitude
B	Dimensionless parameter
c	ω/k , the phase velocity
c_g	Group velocity
C_m	Virtual (added) mass
D	Ship draft
F_r	Restoring force
g	Acceleration due to gravity, 32.2 ft/sec^2
G	Element slope matrix
h	Water depth, ft
H_n	Hankel function of the first kind of order n
$H_{1/3}$	Significant wave height
i	Imaginary number
k	Wave number
k_r	Reflection coefficient
L	Length, wavelength
M	Ship mass
n	Integer
n_a	Unit normal vector outward from Region A
N	Interpolation function
r	Spherical coordinate, ft
R_e	Real number
R,m	Mooring line coefficients
t	Time, sec
T	Time, standard wave period
T^*	Line tensile force
T^*_{Brk}	Approximate average breaking strength
T_n	Normal restoring force

u Velocity in x-direction, fps

U Total horizontal velocity, fps

v Velocity in y-direcion, fps

V Velocity

$\forall$ Volume

x Cartesian coordinate, ft; displacement amplitude

y Cartesian coordinate, ft

α Dimensionless parameter

α_n Unknown coefficient

β Dimensionless parameter

γ Phase shift

Δ Area of element

ε Unit elongation

ζ Wave function

η Unit normal vector

θ Spherical coordinate, radians; wave direction

λ Bottom friction factor

ξ Response of harbor

ϕ Total velocity potential, ft^2/sec

ϕ_a Total velocity potential evaluated on boundary a, ft^2/sec

ϕ_I Velocity potential of incident wave, ft^2/sec

ϕ_R Far-field velocity potential, ft^2/sec

ϕ_s Scattered wave velocity potential, ft^2/sec

ω Angular frequency, radians/sec

∇ Gradient operator, ft^{-1}

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